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GEOLOGICAL SURVEY OF CANADA REPORT ON RESULTS AND DELIVERY

2019-2020

Canada

Natural Resources Canada
General Information Product 123e

Geological Survey of Canada
Report on Results and Delivery 2019-2020

Geological Survey of Canada

2020

Permanent link: https://doi.org/10.4095/327219

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Foreword

William E. Logan, the first Director of the Geological Survey of Canada (GSC) submitted his first “Report of progress for the year” to the Government of the Dominion of Canada in 1843. Over 177 years later, Canada’s national organization for public geoscience continues Logan’s legacy, providing relevant geoscience to federal, provincial and territorial governments and industry to inform decision making regarding geological aspects in many areas such as responsible and sustainable energy, mineral and groundwater resource exploration and development, natural resource infrastructure development, and public safety and security.

This year, the GSC has contributed to Canada’s economic success, supporting Canadian sovereignty, land management and public safety and advancing science policy leadership. For example, as described highlighted in this Report, our flagship science and technology (S&T) geoscience programs, Geo-Mapping for Energy and Minerals (GEM) and Targeted Geoscience Initiative (TGI) achieved outstanding results at the end of their funding cycle in March 2020. In fact, an Ernst and Young study released this year estimated that over the past decade, both programs have already generated at least $1.22B in economic benefits, with private industry investing at least $7.30 for every federal dollar.

In addition, GSC foundational science supported Canada’s Arctic Ocean submission filed with the United Nations Commission on the Limits of the Continental Shelf (CLCS) to define the outer limits of its continental shelf in the Arctic Ocean. Our Marine Conservation Target program has provided science-based estimates of offshore petroleum resources potential, which have supported land use decisions for the offshore and helped Canada exceed its international commitment to conserve 10% offshore and coastal lands by 2020. Our programming, as described in this report, related to cumulative effects, clean energy, emergency management and impact assessments have supported federal, provincial, territorial and Indigenous policy, regulatory and land management needs in Canada.

As we look to the future, work over 2019-20 has positioned us well to advance the next generation of geoscience in Canada. Our scientists and analysts are pursuing geoscience excellence through the GSC’s organizational modernization initiative “Generation 8,” launched last year to facilitate the achievement of our objectives by supporting the integration of data, data analysis and digital technologies, such as artificial intelligence, throughout the Canadian geoscience innovation ecosystem. We are working collaboratively with other federal departments, provinces, territories, northern and Indigenous communities, industry and academia to advance our strategic science research agenda to take advantage of the new frontiers of geoscience, including through the federal “TerraCanada” Science Plan, the development of a Pan-Canadian Geoscience Strategy (as a key action under the Canadian Minerals and Metals Plan). GSC also collaborates internationally, on joint work plans around critical minerals and bringing the community of world geological surveys together.

The entire GSC management team has exercised unflinching leadership and operational management of the largest science and technology DG-level Branch in the Department. We strive to promote a healthy and inclusive workplace, demonstrating care and engagement with staff through several initiatives such as the “Making GSC Ottawa a Better Workplace”, “Together for Respect”, “Kairos Blanket exercise on Indigenous history,” team building excursions, and promoting women in science, through all six GSC divisions across the country. This commitment to engagement with our staff has been especially important this year, as the GSC, and in fact the country as a whole, faced the COVID-19 pandemic. As our work shifted from the office to our homes, our staff has continued to deliver on their priorities, demonstrating exemplary performance and ensuring NRCan’s important work can continue, including work towards achieving the objectives of our GSC 2018-2023 Strategic Plan.

I am proud of the work of the Geological Survey of Canada this year, and honoured to present this 2019-20 Report on our Results and Delivery.

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Lands and Minerals Sector, Natural Resources Canada
Ottawa, Canada

Table of Contents

List of Tables

List of Figures


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Executive Summary

The Geological Survey of Canada (GSC) is an integral part of Natural Resources Canada's (NRCan) Lands and Minerals sector. This national organization for science and technology research is dedicated to providing authoritative geoscience expertise, knowledge and products in support of decision making about Canada's lands and resources.

This Report on Results and Delivery provides an overview of the GSC, its corporate results and delivery structure, and 2019–20 S&T program highlights, as delivered through 14 science programs/services.

This report highlights the GSC's contribution to NRCan's three core, mandated responsibilities: 1) Natural Resource Science and Risk Mitigation; 2) Innovative and Sustainable Natural Resource Development; and 3) Globally Competitive Natural Resource Sectors.

In 2019–2020, the GSC:

- Had budget expenditures that totaled $62M;
- Employed 439 full time employees; and
- Published 894 publications.

Introduction

The Geological Survey of Canada (GSC) is Canada's national organization for public geoscientific information and research. Its expertise focuses on the sustainable development of Canada's mineral, energy, and water resources; the stewardship of Canada's environment; the management of natural geological and related hazards; and the development of technological innovation and support for the competitiveness of Canada's geological resources.

Founded in 1842, the GSC has remained relevant to successive generations of Canadians by:
Working on issues that matter to Canadians;

- Working on issues that matter to Canadians;
- Networking within the lands and minerals innovation ecosystem;
- Supporting a targeted career-long employee learning environment, enabling staff to remain current;
- Ensuring employee access to professional and learning resources required to remain innovative; and
- Enabling a national lands and minerals ecosystem community.

First signed in 1996 and renewed in 2002, 2007, 2012 and 2017, the Intergovernmental Geoscience Accord (IGA) provides a framework for cooperation and collaboration among the federal, provincial and territorial geological surveys. Cooperation and collaboration minimize overlap and duplication, enhance synergies among jurisdictions to resolve regional geoscience problems, and facilitate optimal utilization of resources.

As an integral part of Natural Resources Canada's (NRCan) Lands and Minerals Sector (LMS), the mission of the GSC is to provide authoritative and cutting-edge geoscience information reflected through the following main priorities:

- Geological Knowledge for Canada's Onshore and Offshore Lands;
- Geoscience for Sustainable Development; and
- Geoscience for Keeping Canada Safe.

Geoscience is the scientific study of the planet Earth and its many different natural geological systems. Geoscience is an important tool in helping decision makers develop science-informed solutions to many of society's complex problems. For example:

- Finding natural resources such as minerals, metals, groundwater, and hydrocarbons.
- Helping ensure that natural resources are developed in a responsible and sustainable manner.
- Reducing loss from natural hazards, (e.g., earthquakes, floods, landslides, hurricanes, tsunamis, volcanoes) and climate change (e.g., melting permafrost, sea level changes).

- Understanding natural baseline environmental conditions and human impacts on the environment.
- Landmass mapping to improve our fundamental understanding of the connections and processes between onshore and offshore areas.
- By understanding the history of our planet, geoscientists can better predict how events and processes of the past might influence the future.

Most GSC science programs are developed as inputs to support federal policy, or are instruments of federal policy. For example, among other things, the provision of public good geoscience has been used to:

1. Support Canada's economy.
   - An historical study of Canada's public geoscience programs estimated that $1 of public geoscience investment yielded $5 of exploration spending and discovery of about $125 in new resources.
   - In alignment with this, Ernst and Young (January 2020) provided an economic assessment of NRCan's two major geoscience programs over the past decade, Geo-mapping for Energy and Minerals (GEM) (~$200M, 2008-2020) and the last two phases of the Targeted Geoscience Initiative (TGI-4 and TGI-5) (2010-2020), and determined that both programs have already generated at least $1.22 B of economic benefits, with private industry investing at least $7.30 for every federal dollar. It is noteworthy that these are minimum values, as the study did not project to the expected continued future use and impact of public geoscience products. In addition, to date:
     - » GEM and TGI products have been used for diverse purposes: 22% - to identify areas of resource potential; 26% - for exploration and extraction; 15% - for educational purposes; 11% - for site selection, 12% - for regional planning; and 15% - other.
2. Support science based/informed decision-making.
   - For instance, public geoscience reduces the environmental risks of resource development, informs environmental assessments, and supports international obligations and relationships through scientific collaboration and science diplomacy (e.g., United Nations Convention on the Law of the Sea Program).
3. Inform the development of standards such as national building and transportation infrastructure codes in areas at high risk of geohazards such as earthquakes, clays susceptible to liquefaction, melting permafrost, coastal erosion, and tsunamis.

Through the provision of targeted public-good geoscience, the GSC continues to help ensure that Canada's lands and offshore natural resources and associated sectors (e.g., exploration, mining, and transportation) can help address current and future federal economic, social, and environmental policy priorities.

This document presents a high-level corporate overview of the GSC, its science programs, and program linkages to NRCan and LMS priorities.

Mandate

The GSC has a number of legislated obligations under various federal acts (e.g., *Department of Natural Resources Act* [1994], *Resources and Technical Surveys Act* [1985], *Canadian Environmental Assessment Act* [2012]. In addition, it provides support to the Minister of Natural Resources, as well as to other implicated ministers, to help meet objectives outlined in their mandate letters, horizontal interdepartmental priorities, international processes and federal geoscience commitments outlined in federal budgets[1].

The principal mandate of the GSC includes:

- "Make a full and scientific examination and survey of the geological structure and mineralogy of Canada" (*Resources and Technical Surveys Act*, 1985);
- "Seek to enhance the responsible development and use of Canada's natural resources and the

competitiveness of Canada’s natural resources products” (*Department of Natural Resources Act*, 1994);
- “Have regard to the sustainable development of Canada’s natural resources and the integrated management thereof” (*Department of Natural Resources Act*, 1994); and
- Provide expert information to support environmental assessments under the federal government’s requirements under Bill C-69, which enacts the *Impact Assessment Act* and repeals the *Canadian Environmental Assessment Act*, 2012.

The GSC develops geoscience knowledge and tools in support of its federal mandate. This is a never-ending task due to the need for new resources (e.g. critical minerals, minerals and metals for a low-carbon future), the many uses and applications of geological knowledge (e.g. understanding hazards and risks, climate change, groundwater, etc.), and evolving/changing federal priorities (e.g. Indigenous knowledge, cumulative effects, new natural-resource development infrastructure).

The GSC’s Mission is to provide authoritative geoscience knowledge to inform the stewardship of Canada’s onshore and offshore lands, to sustain responsible resource development for future generations, and to keep Canada safe from natural hazards and related risks.

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[1] *For example: Budget 2013 committed to the Geo-mapping for Energy and Minerals Program, Budget 2015 committed to the Targeted Geoscience Initiative-5.Budget 2017 committed to the Pan Canadian Framework on Climate Change, Budget 2018 committed to Impact Assessment Act (cumulative effects and impact-assessment research). Lastly, Budget 2019 committed to the United Nations Convention on the Law of the Sea Program and the Emergency Management Strategy for Canada.*

Table 1. Geological Survey of Canada Management Team (as of March 31st 2020)

Director General	GSC Division	Director	Program / Service files	Provincial / Territorial Liaison	International Liaison
Daniel Label	**Pacific Division:** Sidney & Vancouver, British Columbia	Sonia Talwar	Public Safety Geoscience	British Columbia	Asia, Latin America
	Calgary Division: Calgary, Alberta	Sonya Dehler	Geoscience for New Energy Supply; Marine Conservation Targets	Alberta, Saskatchewan	India, Russia
	Northern Division: Ottawa, Ontario & Canada Nunavut Geoscience Office, Iqaluit, Nunavut	Linda Richard	Geo-mapping for Energy and Minerals; Impact Assessment Service; Open Geoscience; Canada in 3D	Nunavut, Northwest Territories, Yukon	Africa
	Central Division: Ottawa, Ontario	Geneviève Marquis	Targeted Geoscience Initiative; Science Laboratory Network	Ontario, Manitoba	Australia, United States, China
	Quebec Division: Québec, Quebec	Andrée Bolduc	Groundwater Geoscience Program; Environmental Geoscience Program	Quebec, New Brunswick	Europe
	Atlantic Division: Dartmouth, Nova Scotia	Stephen Locke	Climate Change Geoscience; Marine Geoscience for Marine Spatial Planning	Nova Scotia, Prince Edward Island, Newfoundland and Labrador	Ocean initiatives, United Nations Framework, Convention on Climate Change (UNFCC), Intergovernmental Panel on Climate Change (IPCC)
	United Nations Convention on the Law of the Sea: Dartmouth, Nova Scotia	Mary-Lynn Dickson	United Nations Convention on the Law of the Sea (UNCLOS) Program		A5 nations: Denmark, Norway, Russia and the United States; US Great Lakes Bottom Mapping SC; GEBCO-Seabed 2030

Organizational Structure

The GSC is led by a Director General who provides overall leadership on GSC files. Six regional divisions across Canada share program delivery and provincial and territorial liaison responsibilities for the GSC. The GSC also has an office led by a Director dedicated to helping Canada meet its commitments under the United Nations Convention on the Law of the Sea and the Canada-Nunavut Geoscience Office (CNGO) (Table 1).

In 2019–20, the GSC budget expenditures totaled $62M (Table 2). Its workforce included 439 full-time equivalent (FTE) employees. Of these employees, 82% (360) were indeterminate employees (permanent), 11% (50) term employees and 5% (20) casuals (work for 90 days). The GSC also employed 39 students (9 FTEs or 2% of employees) as part of a targeted approach to developing highly qualified personnel. In addition, the GSC has the honour of hosting 32 emeritus scientists - former GSC scientists who, amongst other things, continue to mentor GSC scientists and complete work they began while they themselves were GSC scientists.

Table 2. Geological Survey of Canada 2019-2020 Budget Expenditures

GSC 2019-2020	A-base ($)	C-base ($)	Total ($)
Vote 1 – Salary	38,355,224.18	5,667,452.43	44,022,676.61
Vote 1 - Operation and Maintenance (O&M)	2,801,569.70	11,815,417.14	14,616,986.84
Vote 5 - Major Capital	316,532.89	1,844,487.35	2,161,020.24
Vote 10 – Grants	18,797.03	1,032,233.00	1,051,030.03
Total All Votes	41,492,123.80	20,359,589.92	61,851,713.72

GSC Results and Delivery

GSC reporting structure within the Government of Canada

The Government of Canada's *Policy on Results* supports a strong focus on results, helps the government track and report progress, assesses effectiveness, and aligns resources to priorities. The GSC results and delivery processes and tools are nested as follows: (from the highest level to the most granular, Table 3):

- Natural Resources Canada Department Results Framework (DRF) (Annex I);
- Natural Resources Canada's Lands and Mineral Sector's Performance Information Profiles (PIP) (Annex I);
- GSC Strategic Priorities (Annex I); and
- GSC Science programs/services (Annex II).

Find more information on results, financial and human resources related to the 2019-20 Departmental Plans on GC InfoBase.

GSC Strategic Priorities

To guide its programs/services, the GSC's Strategic Plan identifies five key priorities for 2018-2023, along with related initiatives to support the priorities' implementation. Priorities include:

1. Geological Knowledge for Canada's Onshore and Offshore Lands;
2. Geoscience for Sustainable Development;
3. Geoscience for Keeping Canada Safe;
4. Geoscience for Society; and
5. Our Science, Our People.

Priorities 1-3 outline the key scientific contributions to Natural Resources Canada's strategic priorities by producing new geoscience knowledge and are aligned with DRF and LMS PIP priorities. Priorities 4 and 5 describe organizational and business objectives to sustain capacity and foster a healthy work environment that is required to conduct efficient, effective, and relevant work.

In Table 3, the right-most columns feed into the left ones in a hierarchical fashion (from GSC to LMS to NRCan). Columns in darker shades represent actual reporting structures and columns in lighter shades represent umbrella structures some of which provide inputs into higher level reporting structures. More information about NRCan's DRF can be found online.

The GSC delivers its science through 14 programs/initiatives/services, which further break down into projects and activities (Table 5; Annex II). Through its programs/services, the GSC engages with Indigenous communities and supports decision-making by communities.

GSC Science Programs/Services

The GSC develops S&T and other geoscience information products to support government policy, regulatory decision-making, or policy implementation. Like other policy instruments, the uses of S&T are as varied as the purposes of the policies themselves; for example, over the years GSC S&T has been used to:

- Support economic development;
- Support regulatory and policy development;
- Demonstrate compliance with international

Table 3. Geological Survey of Canada's Results & Delivery Reporting Structure

NRCan DRF Core Responsibility	NRCan DRF Program	LMS PIP	LMS PIP Projects	GSC Strategic Priority (SP)	GSC Science Programs / Services
Natural Resource Science and Risk Mitigation	Geological Knowledge for Canada's Onshore and Offshore Lands	Geological Knowledge for Canada's Onshore and Offshore Lands	Geo-mapping for Energy and Minerals Canada's Extended Continental Shelf Program	SP-1: Geological Knowledge for Canada's Onshore and Offshore Lands	Geo-mapping for Energy and Minerals United Nations Convention on the Law of the Sea (UNCLOS) Program Canada in 3D
	Geoscience for Sustainable Development	Geoscience for Sustainable Development	Environmental Studies and Assessment Groundwater Geoscience Targeted Geoscience Initiative Geoscience for New Energy Supply	SP-2: Geoscience for Sustainable Development	Impact Assessment Service Environmental Geoscience Program Groundwater Geoscience Program Targeted Geoscience Initiative Geoscience for New Energy Supply Program Marine Conservation Targets Program Marine Geoscience for Marine Spatial Planning Program
	Geoscience for Keeping Canada Safe	Geoscience for Keeping Canada Safe	Geo-hazards and Public Safety	SP-3: Geoscience for Keeping Canada Safe	Climate Change Geoscience Program Public Safety Geoscience Program
				SP-4: Geoscience for Society	Open Geoscience Network
				SP-5: Our People, Our Science	Science Laboratory Network

agreements;
- Develop national and international standards;
- Supply public-good products and services;
- Support public health and welfare for civil and national safety, and environmental protection;
- Provide knowledge and technologies to anticipate and respond quickly to national priorities;
- Support domestic and international diplomacy;
- Assert sovereignty at home;
- Support nation building;
- Meet domestic and international obligations;
- Incent behavioural change; and
- Ensure that international policy is based on scientific principles.

In order to conduct its S&T, the GSC collaborates with scientists across Canada and the world. For example, over the last five years, GSC scientists have published peer-reviewed papers with coauthors from 113 different countries (Figure 1).

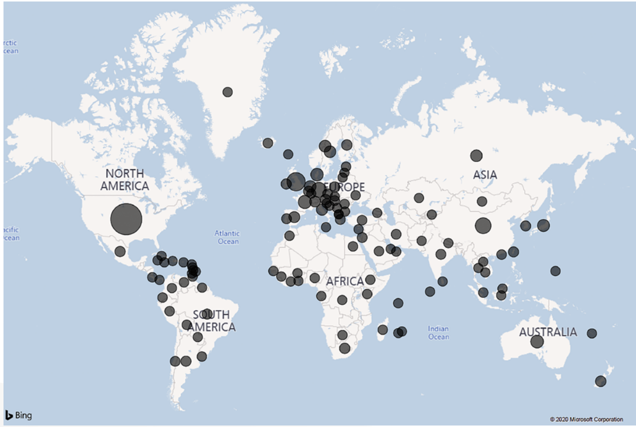


Figure 1. In 2014-2019, GSC publications had coauthors in 113 different countries**.**

Program of Energy Research and Development

The Office of Energy Research and Development (OERD) is the Government of Canada's coordinator of energy research and development (R&D) activities. Thirteen federal departments and agencies receive funds from OERD to undertake R&D and technology demonstrations. OERD is responsible for seven programs including amongst others the Program of Energy Research and Development (PERD). Since the 1970s, the GSC has been collaborating with PERD to develop science to help ensure a sustainable energy future for Canada in the best interests of both our economy and our environment.

GSC received funding for eight new projects in 2019-20, under the new Federal S&T funding of the OERD that updated the former PERD program. These projects address a variety of strategic priorities around more efficient and cleaner energy.

Highlights of 2019-20 activities include:

- Looked at the occurrence and distribution of hydrogen sulfide (H_2S) in the Montney Formation in the Western Canada Sedimentary Basin (WCSB), both to better understand the structural and biological factors that govern the occurrence of H_2S, and to investigate the diagenetic processes involved in H_2S generation. Collaborators include the Alberta Geological Survey and BC Oil and Gas Commission, as well as the University of Calgary seismology and geomicrobiology groups, and initial findings were published.
- A new study has commenced that aims to better understand the interaction of carbon dioxide (CO_2) and rock in reservoir conditions, with applications for enhanced oil recovery using CO_2 injection. A workflow is being developed to observe the flow of CO_2 at reservoir pressures and temperatures, and preliminary results were recently published for the Williston Basin shales and mudrocks.
- Collaborations were established with Canada Centre for Mapping and Earth Observation (CCMEO) and various partners in B.C. and elsewhere to use InSAR data from the new RadarSat Constellation Mission satellite to monitor slopes near Valemount, BC as part of pipeline geohazard studies.
- Results of a multiyear study (started under previous PERD cycle and with several collaborators from Simon Fraser University, Yukon Geological Survey, University of Northern British Columbia, United States Geological Survey and Utah State University) of past seismic activity of the Denali fault, along the Alaska Highway in southwest Yukon, were published in early 2020.

  Environmental and geohazard studies in the Beaufort Sea continued, building on work funded in the previous PERD cycle during which repeat multi-beam and geophysical mapping revealed that the shelf edge is unstable and portions of the seabed failing and degraded over the four year survey period. The project will continue to assess active seabed features that may be related to permafrost degradation and migration of subsurface fluids and gas to the surface and linked to possible environmental factors such as atmospheric methane flux, release of contaminants such as mercury into the marine environment, and carbon cycling. The project has established collaborations

with international agencies, the Canadian Hydrographic Service and the Ocean Sciences Division of the Department of Fisheries and Oceans Canada.
- Flowback and produced water samples were collected over a six-month period after hydraulic fracturing operations at a Duvernay well in the WCSB and are being analyzed for their geochemistry composition in the labs.
- Hybrid geothermal production feasibility study titled: “Transforming Tight Oil and Unconventional Gas (TOUG) Resources into Renewable Geothermal Energy: A Feasibility Study within the Western Canada Sedimentary Basin”
- A new hybrid geothermal resource project was launched which is studying the feasibility of producing geothermal resource using the existing fractured horizontal well network in a shale gas play, supporting conversion from a traditional oil/gas production to a lower CO_2-emitting energy production. The initial stage involves data collection and the development of models of heat transport through the horizontal well network.
- Data mining and machine learning (ML) are being used to reveal complex relationships between operational and geological parameters and well performance, to help optimize operations to maximize resource extraction and minimize impact of resource development on environment.
- A newly published scientific paper describes the use of advanced geochemical methods for distinguishing natural from anthropogenic sources of naphthenic acids in groundwater near oil sands tailings ponds, which will form the basis of modelling studies to better understand environmental impact.

GSC science information is open and distributed through the Government of Canada’s GEOSCAN bibliographic database and various social media venues (Annex III).

GSC Science and Technology Success Stories

The following GSC 2019–2020 S&T success stories are aligned with the GSC's strategic priorities (Annex I) and highlight some of the ways GSC S&T is supporting Canada's policy objectives. Annex II presents a high-level overview of the 14 GSC programs/services.

Strategic Priority 1: Geological Knowledge for Canada's Onshore and Offshore Lands

There are three GSC S&T programs within GSC Strategic Priority 1:

- Geo-Mapping for Energy and Minerals (GEM);
- United Nations Convention on the Law of the Sea (UNCLOS); and
- Canada in 3D.Geo-Mapping for Energy and Minerals

Geo-Mapping for Energy and Minerals

NRCan's Geo-Mapping for Energy and Minerals (GEM) Program, first launched in 2008 to modernize and update geological knowledge of Canada's North, completed its second phase on March 31, 2020. The program's 2019-2020 accomplishments include producing the first digital map of Canada's North to minimum modern standards (Figure 2), and developing a comprehensive geoscientific framework for the North that will be available through a web portal. GEM knowledge and data have helped Northern governments, communities, and industry make informed decisions on mineral exploration, infrastructure, and land use, contributing to sustainable development for a strong Northern economy.

GEM Advisory Group of Northerners

Throughout its first and second phases, GEM benefited from an Advisory Group of Northerners (AGN), representing the diversity of the North, and including Indigenous socio-economic development organizations, the private sector and territorial governments. The AGN:

- Provided critical advice that helps the program overcome specific challenges related to the North in program implementation and delivery, and improves access by Northerners to GEM training, jobs, and opportunities. AGN members also advised on communicating with Northerners.
- Advised on approaches to maximize the value of GEM knowledge for local decision-making on resource development and land-use, through increased access by Northerners to geoscience knowledge and value-added knowledge products.
- Provided advice on continued communication with Northerners that will maximize the impact of the program on northern prosperity and decision-making, and establish leading practices in engaging Northerners and Indigenous communities.
- Provided advice to help GEM maximize the involvement of, and benefits to, Northerners and Indigenous communities by identifying relevant initiatives, tools, products, engagement approaches and collaboration

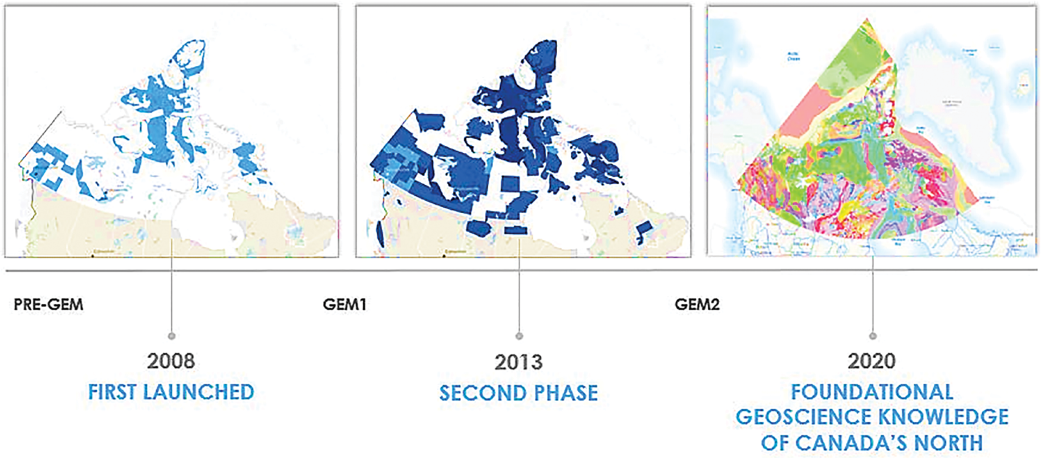


Figure 2. Increased coverage in mapping the Canadian North realized by the GEM Program between 2008 and 2020.

opportunities with communities, all levels of government, industry, and other stakeholders.

Figure 3. Rankin Inlet view from the air, Nunavut.

GEM community research-sharing sessions

GEM conducted community visits and research sharing-sessions before, during and after conducting research, to inform communities and provide them with the opportunity to be involved in research. In 2019-20, these visits focused on presenting final results of the research so that the community could use GEM knowledge as they see fit. Twenty-seven communities were visited in 2019-20 alone, including Atlin, B.C; Dawson, Yukon; Paulatuk, N.W.T.; Pond Inlet, Baffin Island, and Nain, Nunatsiavut ; and Baker Lake, on Hudson Bay, NU. Communications products were developed according to the needs of each community, including satisfying translation needs so that each community received information in its preferred language and dialects.

This important strategic success sets a bar for future work in the North. Community visits demonstrate commitment to building relationships with community leaders and land users, and building trust with representative organizations.

Recent successes include:

GEM Science Accomplishments

Between 2008 and 2020, Phases 1 and 2 of GEM delivered:

- >400 published maps
- Online synthesis of Northern geoscience knowledge via Canada 3D interactive portal
- >450 engagement activities in 65 Northern and Indigenous communities
- >500 opportunities for students and >25 post-doctoral fellowships
- International and Peer-reviewed Geoscience (~2000 publications)
- Grant Program Report (~50 grants)
- Five synthesis bulletins

Grants to academia

Complementing NRCan research, GEM provided renowned academics across Canada close to $3M between 2013 and 2020 ($193K in 2019-20) to support the development of new knowledge and tools that facilitate a better understanding of geology in the North.

Capacity building

From 2013 to 2020, GEM invested close to $1M ($180K in 2019-20) in Northern Indigenous organizations to develop tools and approaches that facilitate the use of GEM knowledge and data and their integration with local and traditional knowledge (for Northerners by Northerners), as well as supporting capacity building across Canada's North.

Science accomplishments 2019-20: Summary

- Continued to advance geological knowledge of underexplored areas of Canada's North.
- Identified geological features relevant to mineral potential in the Mackenzie (kimberlites; carbonate-hosted sulphide deposits), as well as in the Stikina and Cordillera regions.
- Conducted high-resolution mapping of glacial landforms, useful for understanding mineral transport paths and guiding surface mineral exploration in challenging terrain.
- Identified acidic waters in two major rivers of northern NWT having potential impact on local wildlife and indigenous populations that consume these.
- Standardized and integrated available geoscience data in the North into a central repository to aid public dissemination.

Science accomplishments 2019-20: Details

- GEM scientists identified strong potential for additional carbonate-hosted sulphide deposits under the thick glacial overburden between Hay River to Fort Providence.
- GEM scientists identified new potential for kimberlites, unrelated to the Horn Plateau and well up-ice of the Fort Simpson kimberlites.
- Reconnaissance mapping in the eastern Mackenzie Mountains demonstrated that some formations extend much farther east than previously was recognized. This discovery may have economic implications.
- In the Stikinia area, a new framework was developed largely dispensing with the old Cordilleran terrane definitions and improperly defined suture zones. The redefined terranes have a predictable and regionally coherent stratigraphy, geochemistry and mineral potential.
- In the Cordillera, a first direct comparison of fault gouge clay K-Ar dating and calcite fault slickenfibre U-Pb dating worldwide, showed close correspondence between the two methods and enabled identification of a previously unrecognized fault slip event. The calcite U-Pb dating method shows great promise for this and a wide range of applications (Figure 4)
- The Keewatin region, where the largest ice dome of the Laurentide Ice Sheet was located, has the least constrained paleo-ice dynamics history due to incomplete interpretations of the glacial geomorphology. GEM scientists used high resolution imagery (2-m ArcticDEM and 15-m Landsat 8) for mapping an unprecedented number of glacial landforms and to identify coherent glacial land systems
- Discovery of very acidic waters (-1.44 pH) in Northern NWT, having potential impact on local wildlife and Indigenous populations that consume these, identified the need for follow-up research to understand potential toxic metal loading of two major rivers (Horton, Anderson).
- Standardized and integrated available geoscience data in the North (including legacy and pre-GEM) into a centralized repository. At this time, over 94000 stations have been digitized.

United Nations Convention on the Law of the Sea (UNCLOS) Program

Canada ratified the United Nations Convention on the Law of the Sea (UNCLOS) in 2003, and as a party to the treaty has a legal obligation to define its continental shelf beyond 200 nautical miles by filing submissions, making formal presentations, and engaging with the Commission on the Limits of the Continental Shelf during the review process.

In addition to precisely defining the outer limits of its continental shelf following the criteria set forth in Article 76 of the Convention, submissions by coastal states include robust scientific data and arguments showing the continental shelf extends beyond 200 nautical miles and that it is a natural component and a natural prolongation of our landmass. Canada's two submissions (Atlantic Ocean filed in 2013 and Arctic Ocean filed in 2019) show entitlement to 2.4 million km^2 of seafloor and subsoil, making it the largest area ever considered by the United Nations under UNCLOS. International recognition of the outer limits will eventually become Canada's last boundaries on the map, conferring sovereign rights over the living and non-living resources on the seafloor and in the subsoil.

Recent successes include:

Arctic Ocean submission

On May 23, 2019, Canada formally filed its 2100 page Arctic Ocean submission with the Division of Ocean Affairs and the Law of the Sea at the United Nations in New York (Figure 5). With this filing, and that for the Atlantic Ocean in 2013, Canada has now fulfilled its obligation to define its continental shelf beyond our 200 nautical mile Exclusive Economic Zone (Figure 6). More information can be found at Canada's Arctic Ocean continental shelf submission.

To get to this point required ten years (2006-2016) of extensive planning and surveys to acquire bathymetric, geophysical and geological data needed to define the outer limits of the continental shelf. Often this work was conducted under harsh and challenging conditions, especially in the perennially ice-covered central Arctic Ocean in the vicinity of the North Pole and along the Canadian Arctic Archipelago. Through it all, science teams in the Geological Survey of Canada (GSC) and the Canadian Hydrographic Service (CHS) and the legal team in Global Affairs Canada prevailed, producing a submission based on robust scientific data, evidence and legal arguments.

Figure 4. GEM-2 Cordillera science accomplishment: first direct comparison of fault dating methods.

International cooperation is an important aspect of the work carried out by the program, including a key scientific deliverable by Canada to the Arctic Science Ministerial meetings. GSC geoscientists continue to collaborate with colleagues in Denmark, Norway, Russia and the United States on scientific issues related to defining the continental shelf in the Arctic Ocean, including making presentations and conducting bilateral discussions at an annual meeting of these five Arctic nations.

2019 Departmental Impact Award

Contributions by the GSC team to Canada's Arctic Ocean submission were recognized in September 2019, with a departmental Impact Award in Leadership and Innovation.

What's next for the UNCLOS Program?

In June 2019, the UNCLOS Program was informed that a request for five additional years of incremental funding had been approved by the Treasury Board and Finance Department.

The UNCLOS Program has moved into its post-submission phase with an emphasis on publishing and presenting scientific results to the international scientific community, engaging with other Arctic nations on scientific issues related to delineating the continental shelf in the Arctic Ocean, and developing and making a required formal presentation on Canada's Arctic Ocean submission to the 21-member Commission on the Limits of the Continental Shelf at the UN in New York in 2021.

Canada in 3D

Core geoscience knowledge is critical to overall management of the country's landmass and to decision-making related to natural resource development. GSC scientists are working with national and international partners to develop the next generation of 3D geological modelling tools and to explore new approaches to data visualization. The results are being integrated into Canada in 3D (C3D), a national surface and subsurface

Figure 5. Canada's Arctic Ocean submission being filed at the United Nations in New York, May 23, 2019.

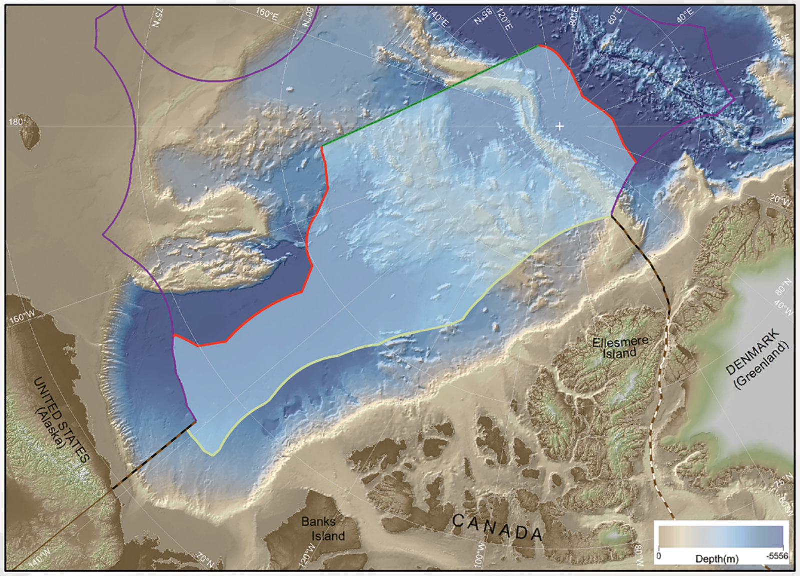


Figure 6. Proposed outer limits of Canada's extended continental shelf in the Arctic Ocean.

compilation of the geology of Canada to help better understand the geological structures and dynamic processes below ground. C3D is more than a series of maps, however. It includes the latest geological knowledge and provides visualization of/and access to three-dimensional data on surficial geology, bedrock geology, and information about the mantle layer. The GSC is working to make C3D publically viewable online and freely and openly available for download. Essentially, C3D is not only creating a synthesis of the geology of Canada, but will also act as an online gateway to it.

Recent successes include:

The GEM syntheses, including surficial and bedrock maps, are being used as a pilot project for the development of a C3D web portal to disseminate the geological knowledge of the North. The portal will be an interactive way to discover Canada's vast and multi-faceted landscape, through a comprehensive 3D model of the subsurface geology of Canada. The C3D web portal will showcase the latest national surficial and geological compilations at various resolutions and all publications, including geological maps and scientific reports, will be publically viewable online and freely and openly available for download.

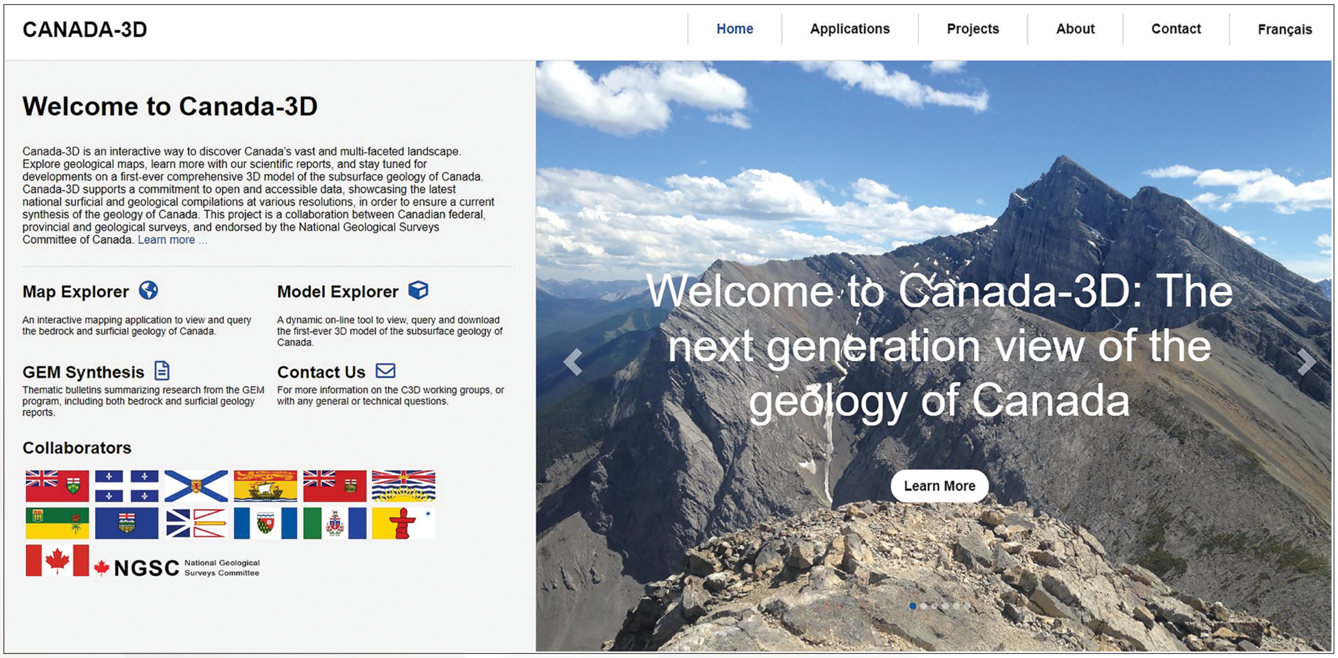


Figure 7. A preview of the Canada 3D web portal.

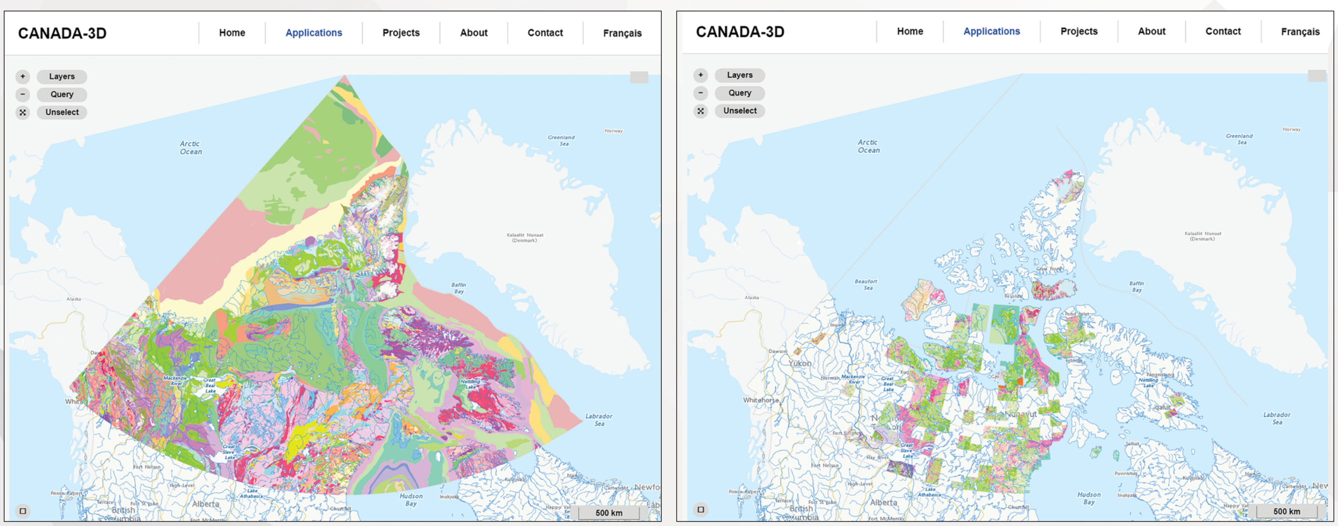


Figure 8. In 2019-20, major progress was made in compiling C3D bedrock and surficial geology maps.

Strategic Priority 2: Geoscience for Sustainable Development

There are seven GSC S&T programs within GSC Strategic Priority 2:

- Targeted Geoscience Initiative (TGI);
- Environmental Geoscience Program (EGP);
- Groundwater Geoscience Program (GGP);
- Geoscience for New Energy Supply (GNES) Program;
- Marine Conservation Targets Program (MCT);
- Marine Geoscience for Marine Spatial Planning Program (MGMSP); and
- Impact Assessment (IA) Service.

GSC commitments to land and marine conservation:

- Assess offshore petroleum resources as part of Canada's target of protecting 10% of its offshore by 2020;
- Develop new maps and analyses of seafloor geology and active seabed processes to inform evidence-based marine spatial planning and regional environmental assessments; and
- Provide geoscience-based environmental-impact statements to support land-use planning and environmentally sound resource development, both on land and in our coastal and offshore waters.

Targeted Geoscience Initiative

Canada's reserves of metals have been declining for decades. Deeper exploration for new resources is required to offset the increasing rarity of surface discoveries. Established in 2000, the Targeted Geoscience Initiative (TGI) is a collaborative, federal geoscience program that provides industry with knowledge and innovative techniques to enhance effective targeting of deeply buried mineral deposits. Using an ore system approach, TGI's thematic research program integrates geoscience data and knowledge on Canada's major mineral systems from locations across the country.

TGI contributes to the departmental goal of supporting economic development of natural resources by generating a wealth of public geoscience knowledge and leading edge methods that propel investment and innovation in the Canadian mineral exploration industry. Over the past decade, TGI has generated over 1000 public geoscience knowledge publications, over 75 industry collaborations, over 500 science presentations to the public and stakeholders, training for more than 150 students, and 48 grants to Canadian academic institutions.

TGI completed its fifth phase (TGI-5) on March 31st, 2020. Research during this phase focused on understanding geological processes that lead to mineral deposition and modelling 3D geological structures at depth to identify potential ore deposits. Recent achievements by the program include the following:

- TGI research has been heavily used by industry, as evidenced by 33 written attestations received by TGI-5. In 2019-2020, TGI-5 received two new industry attestations and produced 45 geoscience publications.
- TGI-5 researchers have produced over 540 publicly available geoscience publications that have been downloaded over 10,700 times to date.
- Two TGI scientists also received prestigious awards for their significant contributions to their fields of study.
- TGI-5 also supported the development of a key implementing arrangement with Geoscience Australia to support collaborative research on geological modelling, including for critical minerals. This agreement was signed in March 2020 and will foster further international collaboration for the GSC.
- In early 2020, TGI-5 hosted a successful grant research workshop and a joint TGI-Geo-mapping for Energy and Minerals (GEM) closeout workshop to bring together GSC scientists, university researchers, and industry representatives to discuss the scientific results and achievements of TGI-5. Knowledge dissemination continues through the upcoming publication of TGI-5 synthesis volumes and a TGI-5 grants research volume, which will highlight key scientific findings of the program.
- In the past year, the importance of TGI research to the Canadian mining industry was also highlighted through a geoscience valuation study on the TGI and GEM programs, conducted by Ernst & Young, which showed that there is a 7.3 economic return on

investment for every dollar invested in GSC mineral geoscience programs.
- TGI-5 also underwent a departmental evaluation in 2019-2020, that was finalized in March 2020. Both the valuation study and program evaluation will inform the development of future avenues of GSC research.

Recent program successes include:

Canada's newest gold mining district

New public geoscience knowledge generated by TGI has helped Canada's newest gold mining district in the Kivalliq region of Nunavut to expand. Agnico Eagle Mines Limited began production at the Meadowbank mine in 2010 and in the Meliadine district in 2019. Production is expected to begin at the Amaruq deposits in late 2019. Previous models used to predict the size, shape and grade of the deposits in this district assumed that the ore zone followed the folds of the Banded Iron Formation (BIF) host rocks; however, lower than expected gold recovery caused mine geologists to question this model.

Making the most of Canada's newest gold mining district

Following the initial establishment of a gold mining district in the Kivalliq region of Nunavut based on GEM research, new public geoscience knowledge generated by TGI has helped this new gold mining district to expand. Previous models used to predict the size, shape and grade of the deposits in this district assumed that the ore zone followed the folds of the Banded Iron Formation (BIF) host rocks; however, lower than expected gold recovery caused mine geologists to question this model. Structural mapping and geochronology work by TGI scientists, students, and collaborators identified that the distribution of gold in the district is controlled by a complex arrangement of faults and folds that developed over millions of years as the rocks underwent changes in pressure and temperature. This discovery improved the search criteria used to find new deposits, enabling expansion of the mining district in the Kivalliq region, and improving the exploration models used to look for BIF-hosted gold deposits around the globe.

Figure 9. TGI's researchers conducting fieldwork from locations across the country.

New model for chromite deposition in the Ring of Fire

The Ring of Fire in northern Ontario is one of Canada's newest districts, discovered in 2007. This succession of mafic to ultramafic intrusive rocks hosts world-class magmatic chromium, significant magmatic nickel-copper-platinum group elements, and potentially economically significant iron-titanium-vanadium mineralization. Future chromium production from the Ring of Fire region could position Canada as one of the five leading producers worldwide; however, improved scientific knowledge of the origins of these commodities was required to support exploration.

Working closely with exploration and mining companies in the area, the TGI-5 research team developed a new model for the formation of chromite deposits in the area. By studying the textures and geochemistry of the rocks encountered in drill cores and comparing deposits in the Ring of Fire to other significant chromite deposits elsewhere in the world, the TGI research team was able to infer that the thick layers of chromite mineralization likely formed by partial melting of surrounding rock and mixing with magmas of specific chemical compositions.

Changing the way explorers operate

In 2012, two large, high-grade deposits were discovered in basement rocks of the Patterson Lake corridor on the southwestern margin of the Athabasca Basin, Saskatchewan. Little was known about how or why these newly discovered deposits had formed at depth outside of the basin, in which uranium is traditionally found.

Following up on this discovery, TGI-5 researchers joined geologists and students from the Saskatchewan and Alberta Geological Surveys, eight industry partners and collaborators from three universities to update the regional geology, structural-tectonic settings and ore deposit model of the Patterson Lake corridor in Saskatchewan, Initial results reveal significant differences in uranium ore genesis that indicate changes are required to the existing exploration model applied in Proterozoic basins in Canada and abroad.

New technology explores deep roots at New Afton

Complete porphyry systems have not previously been imaged from top to bottom, resulting in knowledge gaps regarding their architecture. At the New Afton copper-gold mine in British Columbia (BC), TGI researchers and staff from New Gold Inc., the operator of the mine, completed one of the first applications of Disturbed Acoustic Sensing (DAS) – Vertical Seismic Profile (VSP) for mineral exploration. The goal of this research was to create a picture of the geological structure of this copper-gold porphyry deposit below the surface, deeper than other methods are typically able to achieve.

Mining commenced at New Afton in 2002, which enabled the collection of seismic data using holes drilled underneath the mine's abandoned open pit. The TGI team used a fibre optic cable rather than traditional geophones as an innovative method to collect high-quality seismic data at the site. The 3D models developed from the seismic data provide an unprecedented view of an entire structure of the ore deposit and its relationship to surrounding rock provides clues about how mineralization occurred (Figure 10). The results of this leading edge research will support future exploration activity on porphyry deposits and mining operations.

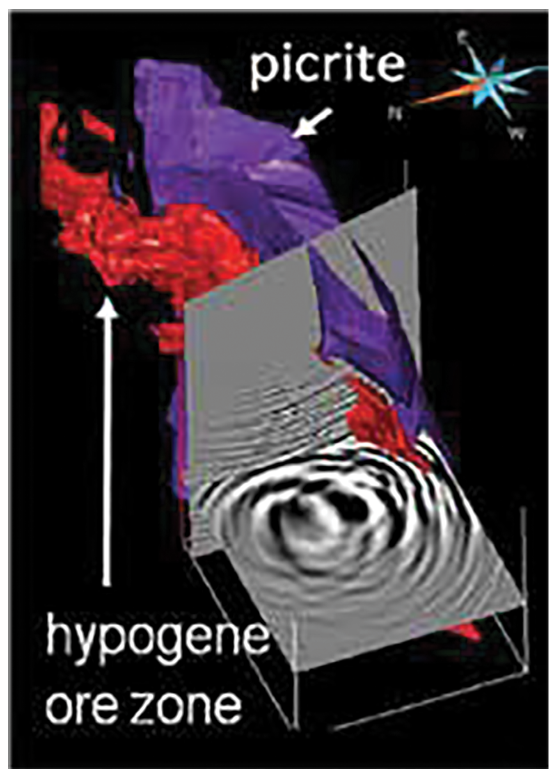


Figure 10. 3D model developed from seismic data.

Innovation generates new opportunities for Volcanogenic Massive Sulphide (VMS) targets

By integrating 3D seismic data with physical rock properties from drill cores, geochemistry and mineralogy of the Lalor VMS deposit in Manitoba (Figure 11), TGI researchers discovered that the seismic data could detect sulphide ore and the conduits of mineralized fluid that once fed metals to the deposit beneath the ocean floor. This is remarkable, considering that multiple geological events broadly deformed and recrystallized the Lalor VMS deposit much later in its history. This innovative methodology provides industry with new opportunities for targeting VMS deposits at greater depths.

Environmental Geoscience Program

The aim of the Environmental Geoscience Program (EGP) is to distinguish the environmental effects of natural-resource development from those produced by natural processes, and to develop new approaches to support the sustainable use and development of Canada's natural resources through informed decision-making.

Recent successes include:

Program renewal

Following a rigorous and transparent process (consultation and workshop to explore new themes, call for Letters of Intent, call for Proposals with peer review) to support new research projects, the next phase of the EGP (2019-2024) was finalized. Eight projects were selected and received funding. Four projects from the previous phase also continue, significantly supported by external funds.

Public presentations

On May 21, 2019, EGP researchers presented their 2014-2019 scientific advances, and researchers who were approved for the 2019-2024 EGP program cycles presented their hypotheses and the research they will lead. These presentations are available on GEOSCAN:

- Public presentations of May 21st, 2019: Environmental Geoscience Program, current status of research projects (phase 2014-2019)
- Public presentations of May 21st, 2019: Environmental Geoscience Program, current status of research projects for the 2019-2024 program cycle on YouTube

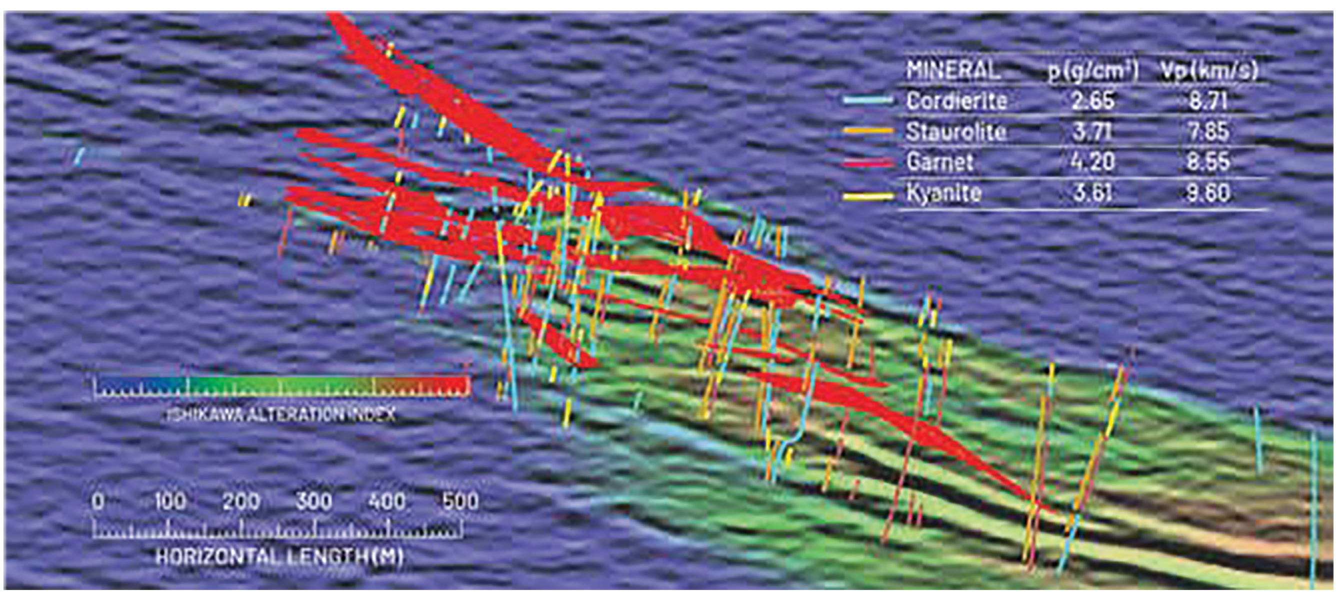


Figure 11. 3D model developed by combining multiple datasets from the Lalor VMS deposit site (Manitoba).

More effective/efficient environmental regulation and oversight

BC Oil and gas commission (BCOGC) thanked EGP induced seismicity project for the SeisComp tool they developed. The SeisComp automated event cataloguing and distribution system allows BCOGC to get notifications within minutes. As a result, they are able to send info to emergency officers ahead of any calls coming in and initiate the response from industry. It has been qualified as an extremely useful tool by BCOGC.

Contribution to a major United Nation initiative

The Technical Background report to the Global Mercury Assessment 2018 of the United Nation Environment Program was released in September 2019. EGP is a main contributor to this assessment. The UNEP Global Mercury Assessment provides the most recent information available for the worldwide emissions to air, releases to water, and transport of mercury in atmospheric and aquatic environments.

International recognition

Dr. Martine Savard, Chief of the Delta Lab of the Geological Survey of Canada in Québec City gave a plenary lecture titled “Learn How Growth Ring Isotopy in the Boreal Forest Reflects the Impact of Atmospheric Nitrogen Emissions” at the first symposium of the International Association of GeoChemistry (IAGC), combining the international conferences of AIG (Applied Isotope Geochemistry) and Water Rock Interaction (WRI), at Tomsk University Polytechnic, Siberia (Figure 12).

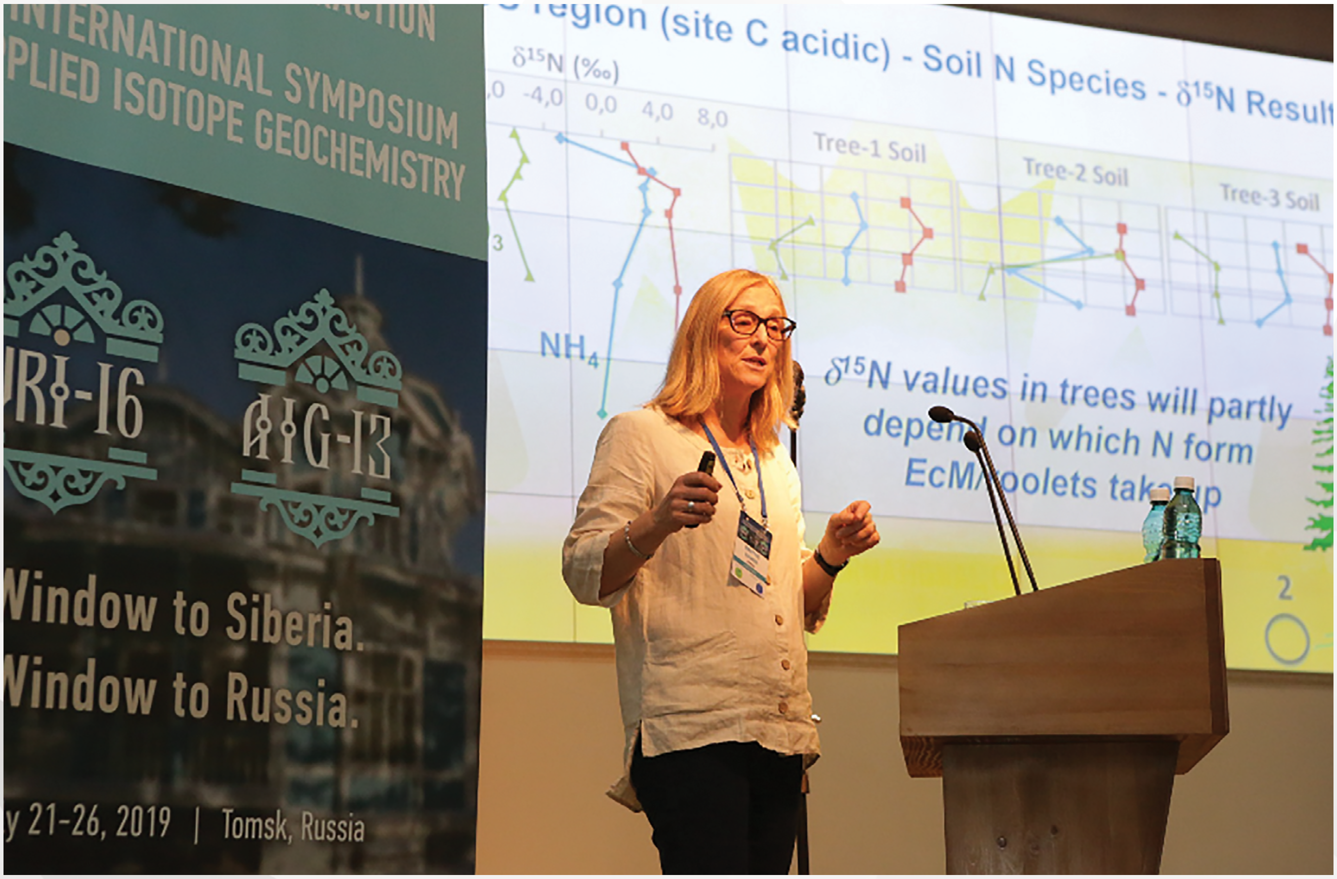


Figure 12. Martine Savard, Chief of the Delta Lab of the Geological Survey of Canada, giving a lecture at the first symposium of the International Association of GeoChemistry (IAGC). Photograph reproduced from an article prepared by Alexandra Lisovaya and Natalia Karakorskova (in Russian): https://news.tpu.ru/news/2019/07/29/35064/

Groundwater Geoscience Program

The goal of the Groundwater Geoscience Program (GGP) is to better understand groundwater distribution, quantity, and flow dynamics within integrated water models for sustainable water management.

Figure 13. Observation well installation in the Vars-Winchester esker near the city of Embrun in Ontario.

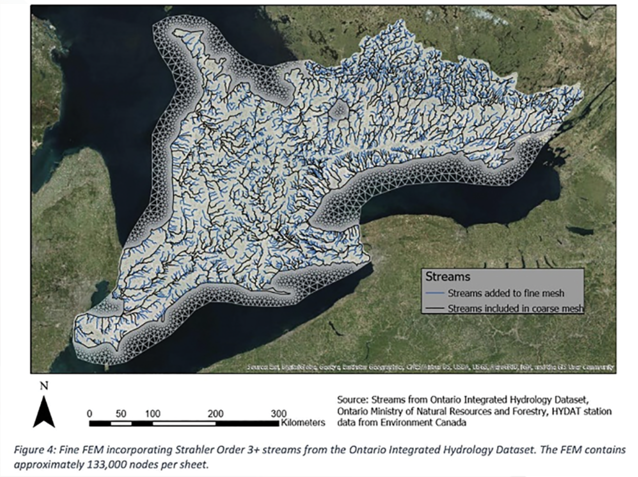
Recent successes include:

A National Dialogue on Groundwater (NDGW) started on January 15, 2020 between the federal, provincial and territorial partners. This new dialogue will occur every couple of months to discuss success stories,

research gaps and improved ways of collaboration at a national scale. This new NDGW format will replace the National Workshop on Groundwater that occurred every five years or so.

A framework for sustainable groundwater management

A 3D geological model has been developed for southern Ontario in collaboration with our partners from the Ontario Geological Survey (OGS) to support development of a regional numeric coupled groundwater–surface-water model for southern-Ontario. Both models have been released into the public domain. The groundwater model is currently being used to support a decision support system developed by the private sector for water forecasting for southern Ontario (11 watersheds) with online information delivery.



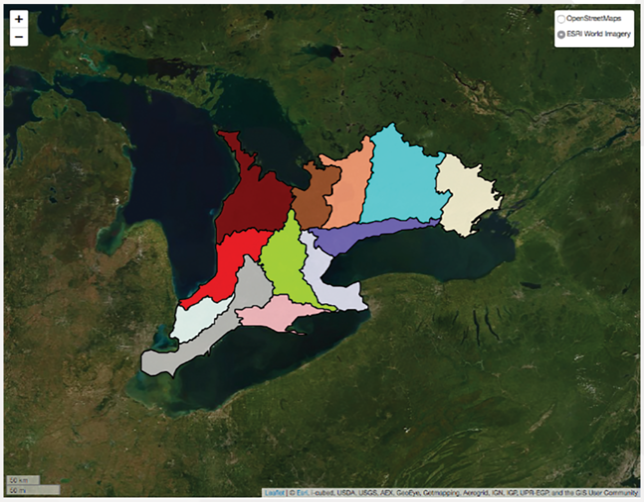


Figure 14. Fine Finite Element Modeling (FEM) of surface and groundwater in Southern Ontario.

Groundwater Information Network (GIN)

- Major progress has been made on the linked data technical infrastructure for Canada-United States and federal Pan Canadian science plan on Climate Change.
- Scientists involved in the GIN project have led an International Geoscience Standards meeting under the auspice of Open Geospatial Consortium (OGC) in June 2019 and they have hosted an International Linked data workshop (OGC SELFIE) in Quebec City in July 2019.

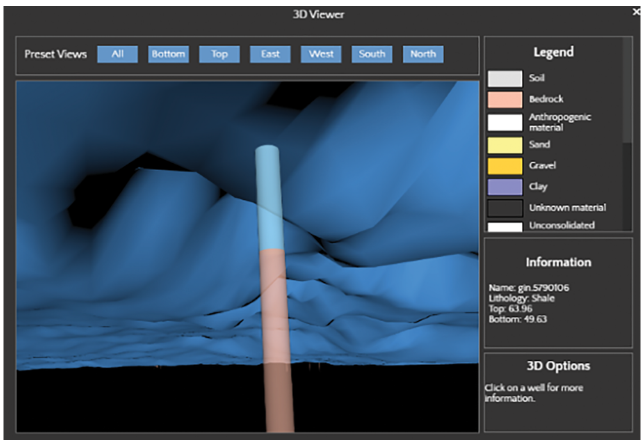


Figure 15. 3D Water Well Viewer for the new GIN portal prototype.

Science plans of the Great Lakes

The GGP has been highly influential in the development of the science plans of the Great Lakes and specifically on the following agreements:

- Canada-Ontario Agreement (COA) under Annex 8 on Groundwater;
- ''Parties' Priorities for Science and Action" under the Great Lakes Water Quality Agreement (GLWQA) (International Joint Commission [IJC]).

In both cases, regional scale integrated surface water/groundwater model developments are becoming a priority in the Great Lakes Basin, for not only Canada and Ontario in particular, but also for the United States as well. To expand on the importance of groundwater resource on water management in the Great Lakes Basin, a plenary discussion entitled "Approaching the 50th Anniversary of the GLWQA: a panel discussion focused on groundwater science in the Great Lakes" was organized during the Regional-scale groundwater geoscience in southern Ontario Open House in February 2020. Scientists and stakeholders discussed the need for a regional scale integrated surface water/groundwater model at the basin scale.

GGP launched a new five years research phase (2019-2024). During the last year of its last phase, the program sent a call to receive new project proposals. Two new projects were selected and two from the previous phase were granted to continue.

Geoscience for New Energy Supply

The goal of the Geoscience for New energy supply (GNES) Program is to support strategies for our transition to a future low-carbon economy through clean-energy research and development and the promotion of non- and low-emitting energy resources using advancements in the fundamental understanding of Canada's subsurface landmasses.

Research partnerships & collaborations are fundamental to GSC program success. For example, GNES collaborations have resulted in increased funding to $1.59M that will bolster the $225k/year budget. This will enable the program to expand its scope into new and exciting innovative areas like cloud computing/machine learning/AI, an increased national knowledge base for the exploitation of geothermal energy, and innovative offshore energy mapping through partnership with the province of Nova Scotia. Collaborations also give GNES researchers access to a larger swath of cutting-edge laboratory facilities and highly specialized scientific equipment housed in other research facilities.

The program is actively providing opportunities in projects with university partners, building on Memoranda of Understanding. Training of highly qualified personnel (HQP) and shared lab capacities contribute greatly to delivery of innovative science and will continue through the remaining three program years.

Recent successes include:

Geothermal Energy

The GNES Program is assessing geothermal potential in three key areas, developing strong partnerships with First Nations, OGD, industry and academia. The Garibaldi Geothermal Project has developed research collaboration of 34 individuals from seven institutions to tackle geothermal geoscience of the Garibaldi Volcanic Belt, BC. Over the course of the 2019 summer (375 person-days in the field), the research teams installed a temporary (two-month) network of 59 three-component seismic sensors along with a distributed acoustic sensor cable, and conducted measurements at 107 magnetotelluric (MT) sites, 79 gravity stations, and 903 stations set up for geological and structural observations.

Figure 16. Photos of multi-disciplinary geothermal research being conducted at Mount Meager, in the Garibaldi Volcanic Belt (BC), to develop new tools that will increase the chances of success for geothermal exploration and development in Canada.

Moreover, artificial intelligence (AI) algorithms based on computer vision were applied to extract linear features in relation to regional tectonic and local volcanic events in the Garibaldi Volcanic Belt. Multiple image tiles from the same area were employed to generate statistically meaningful outputs. In conjunction with newly acquired geophysical data and analysis of field observations, a geological interpretation based on Landsat 8 images brings new insights to improve our understanding of the geothermal resource and its characteristics in the Mount Meager complex. The geothermal resource model currently under development will be used as an analogue to other volcanic complexes in Garibaldi Volcanic Belt for geothermal resource exploration and assessment.
The Regional Geothermal project has developed collaborations with Yukon Geological Survey and Northwest Territories Geological Survey (NTGS), for conducting geothermal studies, initiated a PhD project on fracture control on deep crustal fluid circulation, and produced a preliminary report on community heating needs related to hot sedimentary basins. For the St. Lawrence Lowlands Geothermal project, a collaboration with M. Jean-Sébastien Marcil and Resources Utica has allowed GNES to have access to industrial data (related to brine pumping over several years) that had not been shared before. These represent invaluable data that will allow us to better characterize the targeted unit and thus, better calibrate our numerical model to obtain more realistic and representative results. From this research, GNES is developing heat-flow models using unprecedented datasets from industry to improve the chances of success for geothermal exploration and development in this region.

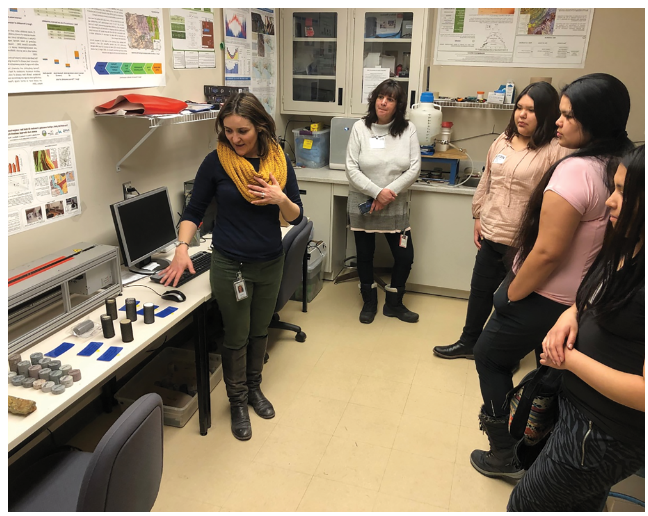


Figure 17. A GNES researcher at GSC-Quebec demonstrating how to measure thermal conductivity on sedimentary reservoir rock samples using an infrared scan as part of the St. Lawrence Lowlands geothermal project to enthused Indigenous high-school students from Abitibi and Côte-Nord. The activity took place as a collaboration with Indigenous Services Canada, in the frame of the activity Initiation to careers in the federal public service.

Clean Energy Resources

Collaboration with the Korean Institute of Geoscience and Mineral Resources (KIGAM) on Liard Basin

(BC) shale-gas potential is ongoing and scientific workshops were held in Banff (June, 2019) and Korea (October, 2019). Fieldwork in the Norman Wells (Northwest Territories, NT) area in collaboration with University of Liverpool was successfully completed and is leading to new understanding of the age and stratigraphy of the key hydrocarbon resources in that region. Stanford University has also expressed interest in collaborating with GSC-Calgary geoscientists in this region.

AI and machine learning (ML) methodology is being developed and applied to facilitate nanoporosity research and other applications to better characterize shale-hosted resources. Such endeavors support new and innovative ways of collecting fundamental geoscience information that can improve our understanding of fluid flow with applications in hydrogen sulphide (H_2S) migration, carbon dioxide (CO_2) sequestration and/or enhanced oil recovery, and geothermal fluid flow in sedimentary successions.

Collaborations with the United States Department of Energy (USDOE) via the Energy and Environment Research Centre at the University of North Dakota (EERC), The Hebrew University (Israel), China University of Petroleum, University of Utah, Oklahoma State University, University of the Western Cape (South Africa) and CanmetENERGY (in Devon, AB) are providing access to international laboratories

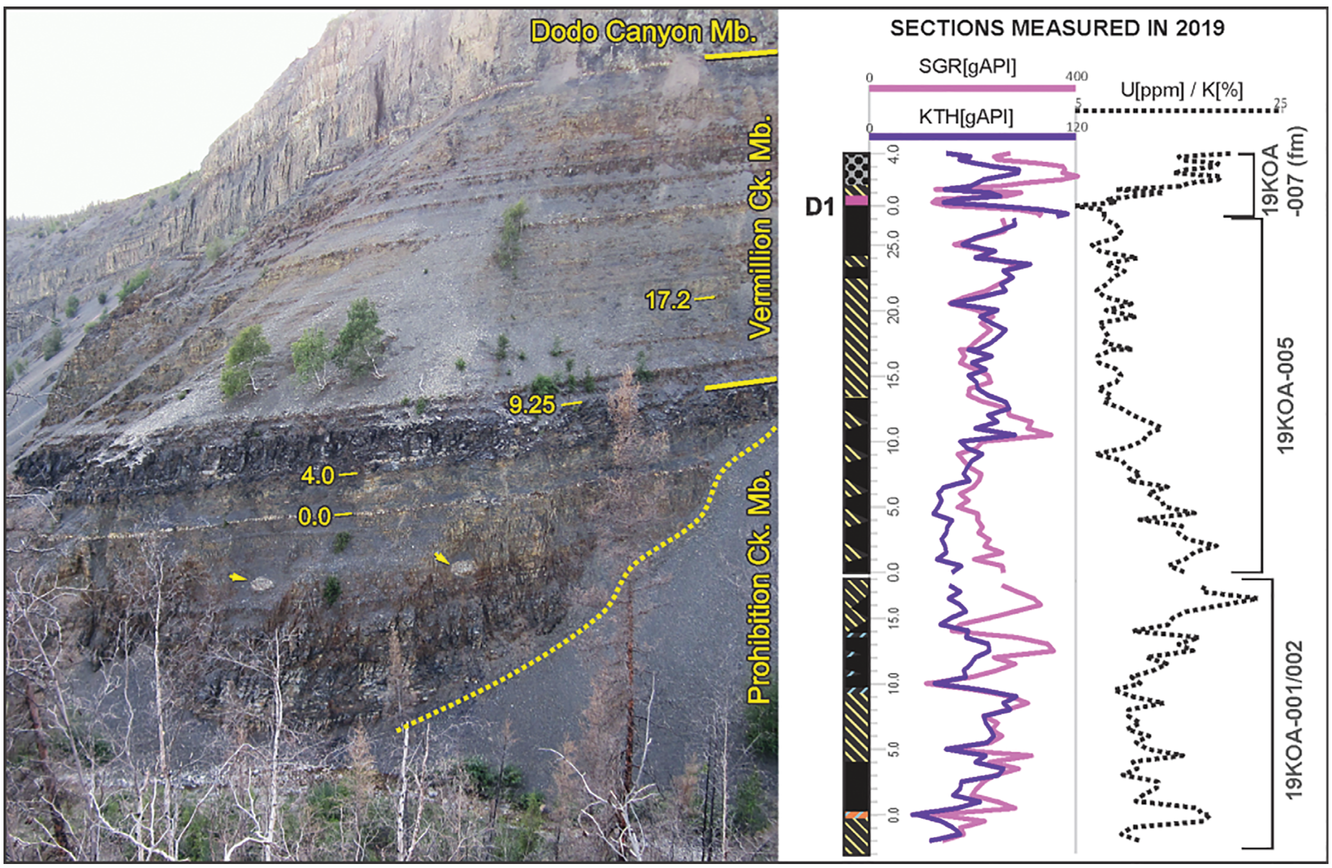


Figure 18. The 2019 GSC – University of Liverpool collaborative field work near Norman Wells, NT, allowed researchers to sample and perform a gamma spectroscopy survey (graphs right of photo) of the Middle-Upper Devonian (388–375 million year-old) black-shale rocks deposited in a continental-shelf marine environment. Their efforts have provided insights and indispensable information about select Earth-system processes that were active at a time when the Earth was experiencing a long-standing (~80 million year) “Greenhouse-like” state. Yellow numbers are meters above a set datum (0.0m); yellow arrows are large (~1.5m-wide) carbonate nodules; interpreted stratigraphic members as labelled.

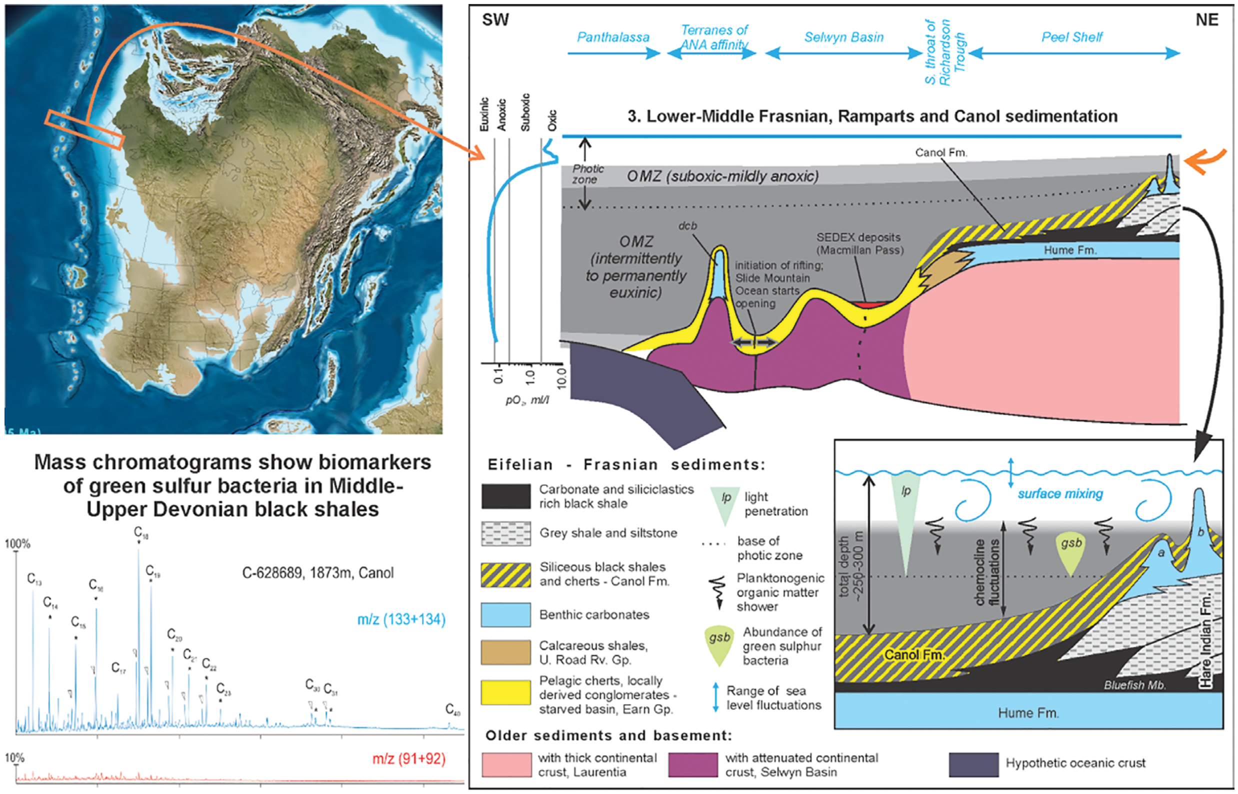


Figure 19. A knowledge compilation of biomarkers from black-shales around the world, combined with new data collected from the Norman wells area of the Northwest Territories, corroborates a school-of-thought that photic-zone, oxygen-free (euxinia) marine continental shelf environments were widespread in the Middle Devonian (ca. 388 million years ago) to Early Mississippian (350 million years ago) time of Earth's past.

and opportunities to advance AI/ML application to geoscience and/or develop and refine laboratory methods related to Canada's energy resources. Successful proposal funding from OERD has also significantly augmented the workforce dedicated to clean energy research.

Innovation and Renewable Energy

The GNES Program has established collaborations with organisations around the world to facilitate the development of new methods. Collaborations were developed with the University of Calgary and the Chinese University of Petroleum (CUP), and a new memorandum of understanding (MOU) was signed with the University of Alberta to facilitate R&D engagement. The GNES Program team held workshops and explored collaborations with Alberta Geological Survey (AGS) and has fully engaged the support of the Saskatchewan Geological Survey (SGS) on nanoporosity research. In the field of organic geochemistry, contributions and collaborations were formally recognized by the University of Utah, the Oklahoma State University, the University of the Western Cape (South Africa) and the Hebrew University (Israel). Furthermore, a Canada–China collaboration is providing new insights on improving the efficiency and accuracy of Canada's energy resource assessments. Nuclear Magnetic Resonance (NMR) techniques are being used to distinguish the responses of various organic- and inorganic- hydrogens in shales and estimate the amount of mobile oil versus adsorbed oil. The technique has its advantage over more traditionally used programmed pyrolysis methods (e.g., Rock-Eval) in that it does not destroy samples to obtain the results, and can analyse larger amounts of samples to improve the sample representation of the resource.

This new method will help improve the accuracy of predictive resource assessments for Canada's oil and gas reserves, and assist in the optimization of production pathways for these resources.

The Hybrid Geothermal project is the first known study of its kind. Under this project, researchers are exploring the use of different energy resources within a specific area as a whole, and are using an integrated approach to ensure the most cost effective, optimized recovery in resource extraction with minimized environmental impacts. The proposed technologic solution is unique as it uses potential energy in compressed natural gas as a driving force for power generation. Then, it considers the use of abandoned gas flow to heat water for improving efficiency in geothermal power generation. Lastly, abandoned horizontal wellbore is used as subsurface heat exchange network, reducing Capex for geothermal resource development.

Marine Conservation Targets

The Marine Conservation Targets (MCT) Program provided science-based estimates of offshore petroleum resource potential to inform decisions related to Canada's target of protecting ten per cent of its offshore lands by 2020. The GSC is responsible for conducting the resource assessments in areas being considered by either the Department of Fisheries and Oceans Canada (DFO) or Parks Canada Agency (PCA). GSC works very closely with the Energy Sector's Offshore Petroleum Management Division (OPMD) as they are responsible for the economic assessment of any petroleum potential in Canada's offshore territory.

GSC's MCT Program ends March 31, 2020 but the GSC should expect further requests for resource assessments in support of Canada's new marine conservation target of 25% by 2025.

GSC geoscience reports and maps are an important and necessary input for marine conservation in Canada – for DFO and PCA decision-makers as well as provincial and territorial governments, Indigenous peoples and local communities. New GSC products released in 2019 include resource assessments offshore Labrador and in the southern Gulf of St. Lawrence. In addition, GSC advice on petroleum potential was a key input in the final support for establishment of the Tuvaijuittuq Marine Protected Area (MPA) by Qikiqtani Inuit Association, the Government of Nunavut and the Government of Canada.

Recent successes include:

Resource Assessment Heat Map

The Marine Conservation Targets (MCT) team mapped areas of high, medium, and low hydrocarbon potential to support federal decision-making. The team developed tools, maps, and reports for decision-makers with varying geoscience backgrounds. Heat maps developed by MCT clearly portray a region's overall petroleum potential (Figure 20). They have been presented to other government departments, non-governmental organizations, First Nations, and community groups.

The MCT Program has assessed broad regions, thereby providing context and planning options, and increasing the value of the GSC work. Completed assessments are publicly available so that GSC products for decision-making are accessible and transparent.

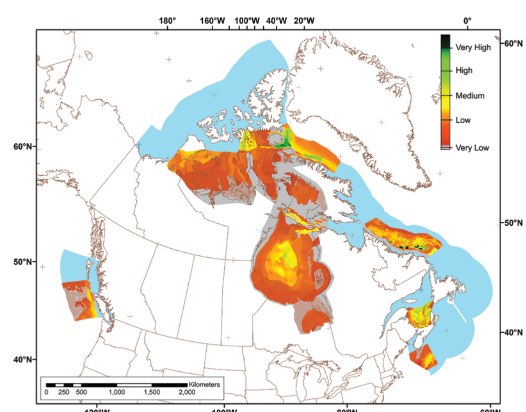


Figure 20. Qualitative resource assessments released publicly as GSC Open Files under the GSC's Marine Conservation Targets (MCT).

Marine Geoscience for Marine Spatial Planning

GSC's Marine Geoscience for Marine Spatial Planning (MGMSP) Program is developing new maps and analyses of seafloor geology and active seabed processes to inform evidence-based marine spatial planning and regional environmental assessments. MGMSP is part of the Department of Fisheries and Oceans Canada (DFO) effort to develop marine spatial plans and atlases for four of thirteen large offshore areas that DFO defines as Canada's bioregions. The GSC's marine geoscience also supports Regional Environmental and Cumulative Effects Assessment processes. The MGMSP is producing new maps of seabed geology for offshore BC (Salish Sea and Pacific North Coast) and offshore Atlantic (Newfoundland and Labrador, and Nova Scotia) that will be uploaded to the Federal Geospatial Platform and accessible through the Marine Spatial Data Infrastructure. Overall, the GSC will produce marine geoscience deliverables at the broad bioregion scale (seabed morphology, geology, and stability), as well as higher resolution assessments to inform specific marine spatial-planning objectives in the Atlantic and Pacific offshore.

Collaborative research

Eight collaborative research projects have been developed to advance MGMSP; all bring either funds, research expertise, platforms or data (five with the Department of Fisheries and Oceans Canada, one with NRCan's Renewable Energy and Electricity Division (REED), one with Nova Scotia, one with Nunavut). With CanmetENERGY and REED, MGMSP evaluated seabed conditions for any potential future offshore wind development in the Maritimes. The MGMSP program has established formal working groups with the DFO for both west and east coasts, to ensure that the best and most appropriate geoscience are accessible for future marine spatial planning.

Recent successes include:

New geoscience data to inform decisions on seabed use

New seabed data were collected in all four bioregion work areas under MGMSP (bathy-LiDAR for Salish Sea, seabed surveys for Pacific Northern Coast, multibeam bathymetry offshore Nova Scotia, and along the North East Newfoundland shelf/slope). Of note, MGMSP collaborated with DFO and with the U.S. National Oceanic and Atmospheric Administration (NOAA) to acquire >20,000 km2 of seabed data in areas being considered for potential conservation measures in offshore Nova Scotia.

Predictive geoscience to predict the distribution of unique seabed habitats

MGMSP used predictive geoscience to remotely predict the distribution of unique seabed habitats. MGMSP mapped the extent, morphology, and setting for glass sponge reef habitat off the British Columbia coast using multi-beam bathymetry, backscatter and sub-bottom geophysics (Figure 21). Their extent was previously unknown to DFO; subsequent video surveys confirmed the presence of these habitats and damage to them from bottom trawling.

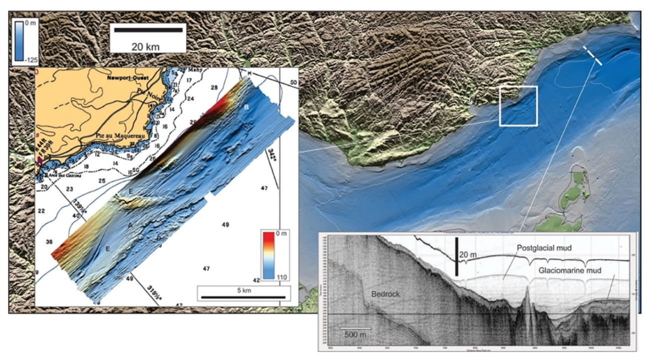


Figure 21. Seabed mapping based on multi-beam bathymetry, backscatter and sub-bottom geophysics.

In 2019-20, MGMSP established eight collaborative research agreements to secure funds, research expertise, platforms or data. For example:

- New bathy-Lidar data were collected with the Canadian Hydrographic Survey (CHS) for mitigation against Fraser Delta super-tide and tsunami flooding;

- > 2 months of joint surveys with CHS to assess seabed geology in a Marine Protected Area and Rockfish Conservation Areas (Figure 21);
- Mapped > 13 000 km2 of seabed
- geomorphology and benthic habitats on north east Newfoundland shelf and slope to allow evidence-based decisions on seabed use (energy, fisheries);
- > 20 000 km2 of seabed data were collected offshore Nova Scotia in a scientific collaboration with DFO and NOAA;
- MGMSP is collaborating with CanMet Energy and Renewable Energy and Electricity Division (REED) to describe seabed foundation conditions for potential renewable energy development in the offshore regions of the Maritimes. The MGMSP report summarizes seabed composition, morphology, stability, and geotechnical properties, based on existing data (Figure 21). The report is expected to be useful for both governments and companies considering future, marine renewable development projects; and
- GSC staff completed successful open water field trials with both deep water and shallow water autonomous underwater vehicles, proving they can effectively support MGMSP science

The GSC advises on shallow seabed conditions offshore eastern Canada based on an extensive, but patchy collection of seabed data. In an upcoming report, the GSC divides Maritime coastal regions into 23 zones, each with its own unique set of seabed conditions. The GSC report uses multibeam vignettes, where available, that show true complexity of the seafloor, and legacy seismic data to illustrate subsurface sediment types and thicknesses.

Impact Assessment Service

The GSC Impact Assessment (IA) Service – formerly named Environmental Assessments (EA) Service – supports land-use planning and environmentally sound resource development, both on land and in our coastal and offshore waters. The GSC is the lead agency for evaluating geoscientific issues in environmental impact statements (EIS). In 2019-20, the GSC provided geoscience expertise for 40 EA projects. Areas included mining (35%), oil and gas (27%), linear and marine related infrastructure (20%), miscellaneous (15%) and nuclear (3%).

Recent successes include:

- The GSC IA contributed to Panel Hearings for two projects: Roberts Bank Terminal 2 (BC) and Milton Hub (Ontario). All concerns will be addressed in Panel Reports.
- This year the GSC IA provided recommendations related to geohazards for the potential of oil and gas development in the North, which were included in the Nunavut Impact Review Board (NIRB) Final Report for the Strategic Environmental Assessment (SEA) in Baffin Bay and Davis Strait, released in July 2019.
- The GSC IA comments on groundwater issues, provided at the Panel Hearing for the Frontier Oil Sands Mine Project proposed by Teck Resources Limited in Alberta, has informed the commitments for the proponent to help reduce the impact on the environment.

Strategic Priority 3: Geoscience for Keeping Canada Safe

There are two GSC S&T programs within GSC Strategic Priority 3:

- Public Safety Geoscience; and
- Climate Change Geoscience Program.

Public Safety Geoscience

The Public Safety Geoscience (PSG) Program develops new and innovative knowledge and tools to support emergency management, development, planning, and regulatory decisions that increase resilience and decrease risk to keep Canadians safe from earthquakes, terrestrial and submarine landslides, volcanoes, tsunamis, and space weather.

Recent successes include:

Contributions to Baffin Bay Regional Strategic Environmental Assessment

With support from Crown-Indigenous Relations

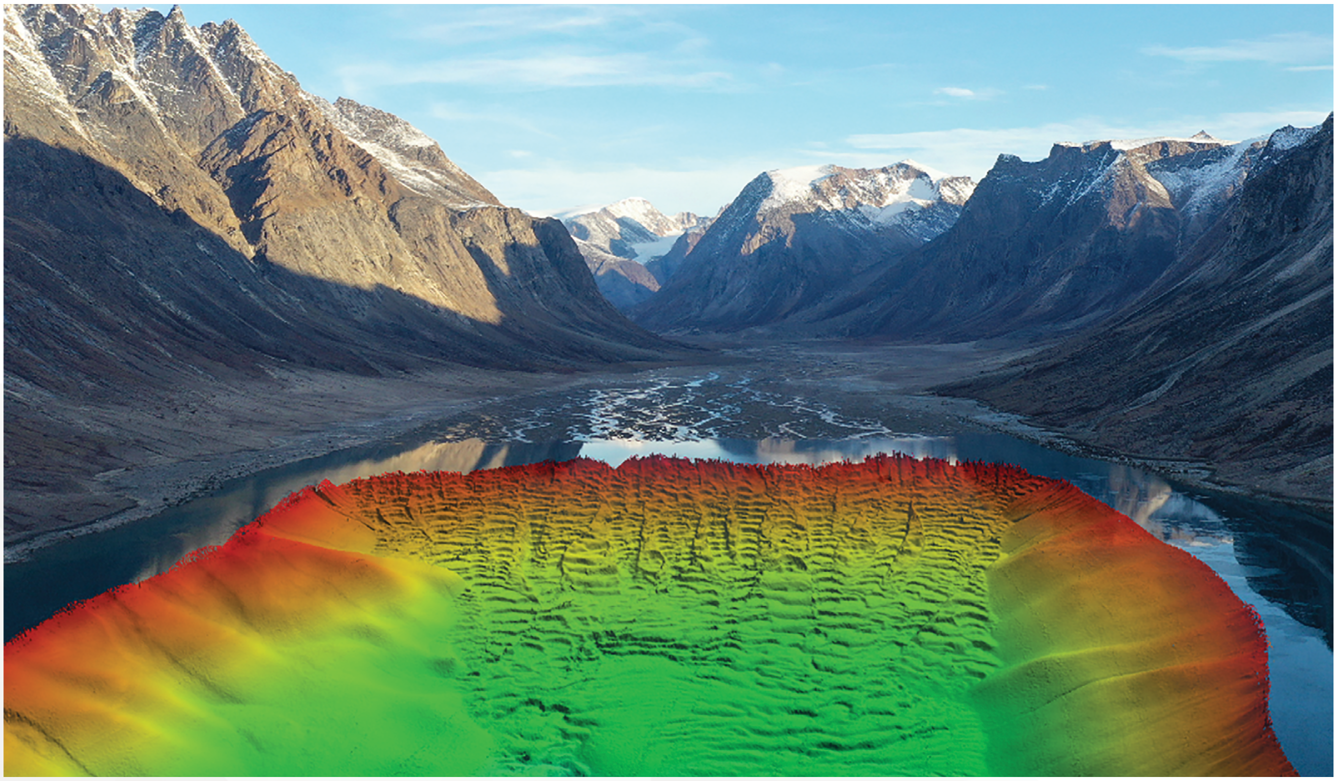


Figure 22. Seabed bathymetry in Pangnirtung Fiord, Nunavut.

and Northern Affairs Canada (CIRNAC), the PSG Program is developing a marine geological hazards framework for Baffin Bay to contribute to a Regional Strategic Environmental Assessment. This will inform development decisions around seabed infrastructure and marine resource activities. There have been reports from communities in the region of waves that have impacted the island, and this work is seeking to understand the causes of such phenomena. New submarine and terrestrial landslides and the effects of scouring from sea ice have been characterized.

New Funding for Geohazard Risk Assessment

Following successful proposals to Defence Research and Development Canada's Canadian Safety and Security Program, the PSG Program received Budget 2019 funding under the Emergency Management Strategy to develop a National Earthquake Risk Assessment Framework. We will collaborate in disaster risk reduction related to coastal hazards and work on regional case studies examining holistic local and regional disaster risk reduction planning. This initiative will deliver a neighbourhood-level earthquake risk profile for Canada, as well as supports evidence-based decision making to reduce earthquake risk.

In 2019-20, the project convened a steering committee that included representatives from Public Safety Canada, Defence Research and Development Canada, the Department of Finance, the Institute for

Catastrophic Loss Reduction, the Canadian Institute of Planners, the Assembly of First Nations, the Metis National Council and the Insurance Bureau of

Canada. The steering committee will guide the work to ensure that it meets the needs of users.

A workshop was hosted in London, Ontario to build capacity for practitioners in the use of the OpenQuake earthquake hazard and risk modelling software that was facilitated by experts from the Global Earthquake

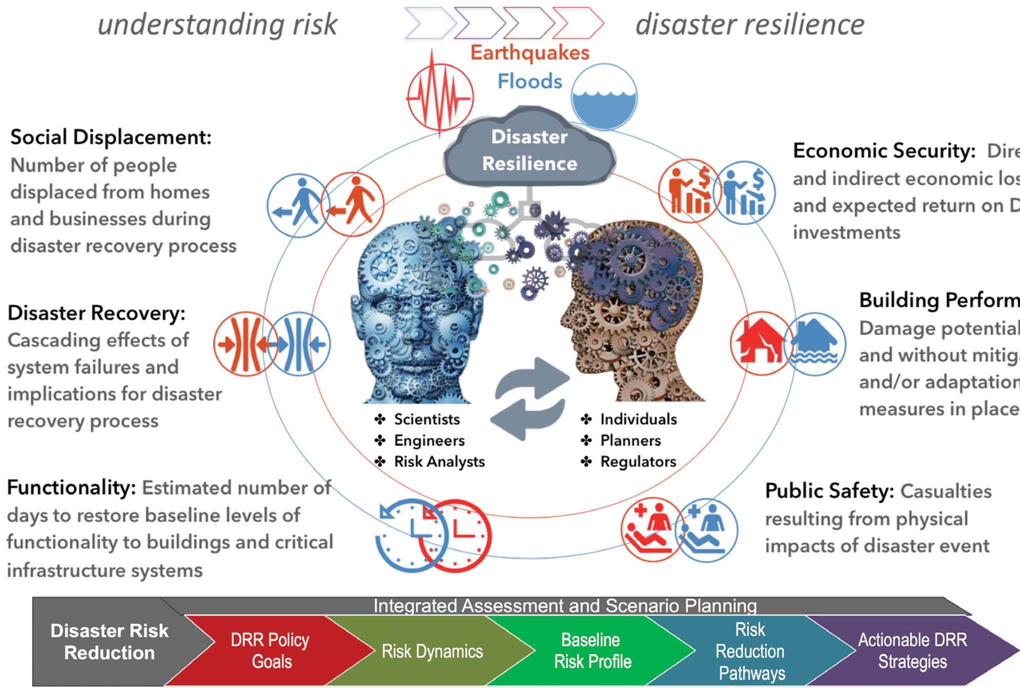


Figure 23. The risk assessment process and indicators to span the science to action spectrum.

Model Foundation. Over 100 people attended the workshop from the private sector, academia, and all levels of government. In addition, project personnel also collaborated with provincial officials in BC to initiate seismic retrofit guidelines for engineers to support assessments of vulnerable buildings.

Tuktoyaktuk Science Day

At the beginning of August, the Hamlet of Tuktoyaktuk, Northwest Territories, home of the Siglit Inuvialuit, hosted a Science Day. It brought together over 200 participants including scientists, federal and territorial government partners, universities and community members to learn about ongoing research in the Western Arctic. Scientists from the PSG Program helped organize the event at which representatives from the GSC, Polar Continental Shelf Program (PCSP) and the Canadian Geodetic Survey took part to share knowledge of NRCan science and programs in the Western Arctic.

Science Day was an effort to bring the research to the community and to encourage scientists and science managers to listen to suggestions from the community on how science can better address the needs of Northerners.

Figure 24. Youth learning about wave action with the Aurora Research Institute wave tank at Tuktoyaktuk Science Day.

Figure 25. Sharing knowledge about science activities in the region at Tuktoyaktuk Science Day.

Space Weather Science for Resilient Infrastructure

Navigation and Satellite System (GNSS) positioning and High Frequency (HF) radio communications are important for aircraft flying over the North Pole but are affected by space weather disturbances. Because of this, the International Civil Aviation Organisation (ICAO) has introduced new requirements for aviation operations. NRCan is one of the centres chosen to supply space weather services. NRCan researchers have established a relationship between geomagnetic activity and GNSS scintillation (that causes GNSS receivers to lose their lock on the signals) which is being used to develop forecasts of space weather effects on GNSS.

Assessing Earthquake Geohazards Project: improving understanding of earthquake hazards across Canada

In Quebec, key partnerships with the Ministère des Transports and Nuclear Waste Management Organisation have provided new information on the earthquake history (paleoseismological records) of southeastern Canada. A summary of some of this work is presented in an NRCan Simply Science article. We are expanding our research in northern Canada through deployment of additional seismic stations and the collection of new GPS data (also documented in Simply Science). In western Canada, a key partnership with Department of National Defence (DND) is providing high-resolution mapping of offshore faults, allowing for more detailed assessments of risk and vulnerability at key DND bases in BC and prioritization of mitigation efforts. Volcanic hazard assessments are being updated in southwest BC using new software developed by partner U.S. Geological Survey. This will allow for prioritization of volcanic hazard research and monitoring efforts.

Figure 26. Tree trunks dating back to the 1663 earthquake are often found partially buried in the ravines bordering the Gouffre River in Charlevoix, QC.

What's new and exciting?

- Investigations into potential new earthquake source zones that will lead to big changes in hazard model (Beaufort Sea subduction zone);
- Development of an active fault database (most active faults in Canada are unknown, but many have been identified across the border in the US), using GNSS, seismic, InSAR, LiDAR, stress and structural data;
- Application of artificial intelligence and machine learning in space weather research;
- Assessment of potential areas and methods for earthquake-triggered and ice-scour generated landslides;
- Development of a second-order tsunami hazard assessment for Canada and work with partners in tsunami hazard and risk research;
- Work with a multi-stakeholder group on volcanic hazard and risk assessment ;
- Incorporation of a multi-hazard and cascading effects approach to hazard and

- risk work;
- Systematically consider the effects of climate change in hazard and risk assessment (landslides, floods and coastal hazards);
- Work with Indigenous communities to incorporate science and Indigenous knowledge in decision making to reduce risk;
- Strong program science contributions to National Risk Profile workshops;
- New interpretations of Kitasu volcano in British Columbia; and
- New Geological Society Special Publication: Subaqueous Mass Movements and their Consequences: Assessing geohazards, environmental implications and economic significance of subaqueous landslides

Climate Change Geoscience Program

The Climate Change Geoscience Program (CCGP) aims to better understand the geological impacts of climate change in Canada, for land-use planning and government regulation and ultimately to help at-risk communities adapt. The program research provides cutting-edge information and data in the areas of climate change hazards, adaptation, and resilience. The GSC, through the CCGP, conducts geological studies on permafrost, coastal erosion, sea level rise, extreme weather events, and glacier melting, to improve our understanding of how Canada's landmass is impacted by climate change and climate-change adaptation.

Collaborative research

In collaboration with the territorial governments, the work related to the development of protocols for mapping (from Earth Observation data) has been used to advance the understanding of how permafrost-related hazards and landscape instability have influenced decision-making in the maintenance of transportation corridors such as the Inuvik-Tuktoyaktuk Highway and the Dempster Highway in Northwest Territories and Yukon.

Recent successes include:

Supporting Adaptation in Permafrost Regions (SAPR) Project: Permafrost science to support development of Canada's Northern communities and infrastructure

Canada's North is rich in largely underexplored and undeveloped natural resources. Sustainable development of these resources could contribute to the North's economy but infrastructure resilient to permafrost conditions is required. The SAPR Project is advancing our knowledge of permafrost. Using a new approach to improve the national permafrost map, better information on ground-ice conditions is available for infrastructure and land use planning, and climate change adaptation.

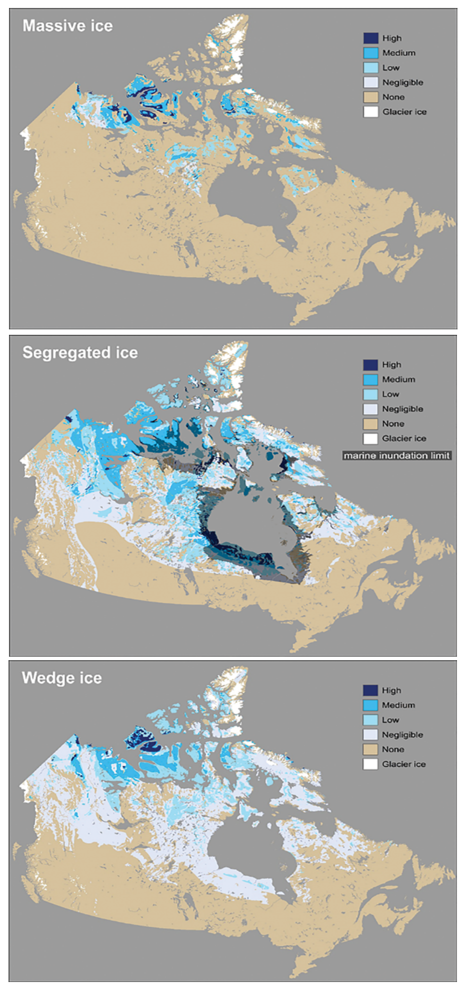


Figure 27. New ground ice maps for Canada using a paleogeographic modelling approach.

The Permafrost Information Network (PIN), a publically web portal, is now available to stakeholders for infrastructure and adaptation planning (Figure 28). Newly developed models, methodologies and mapping protocols improve regional landscape susceptibility modelling. Models show how Canada's northern landscape (key northern transportation corridors are noteworthy) will respond to climate warming. SAPR research also involves the combining of local knowledge with scientific field-based studies and Earth Observation data to improve the knowledge of permafrost conditions in northern communities. This information sharing means better knowledge products and improved climate change risk reduction strategies.

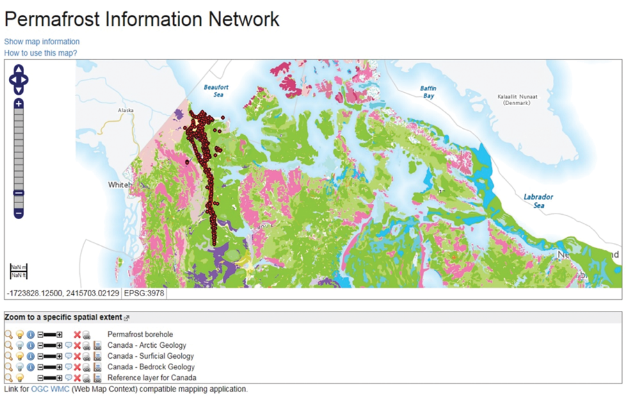


Figure 28. Permafrost Information Network (PIN)

Supporting Adaptation in Coastal Regions (SACR) Project: Understanding of the sensitivity of Canada's coastal regions to climate change

A substantial portion of Canada's population and infrastructure resides along its coasts. Knowledge of present and projected coastal sensitivity contributes to better understanding of the impacts of climate change on Canada's coasts. Impacts along coasts requires knowledge of projected sea level and coastal sensitivity. Sea-level projections help to understand future flooding and assess risk to infrastructure and populations. NRCan's Canadian Geodetic Survey and CCGP scientists partnered to create a national crustal velocity grid, allowing for the generation of relative sea-level projections for all coastal areas. Now, 485 national and regional maps of projected relative sea-level change, through the 21st century, are available for municipal and provincial planning.

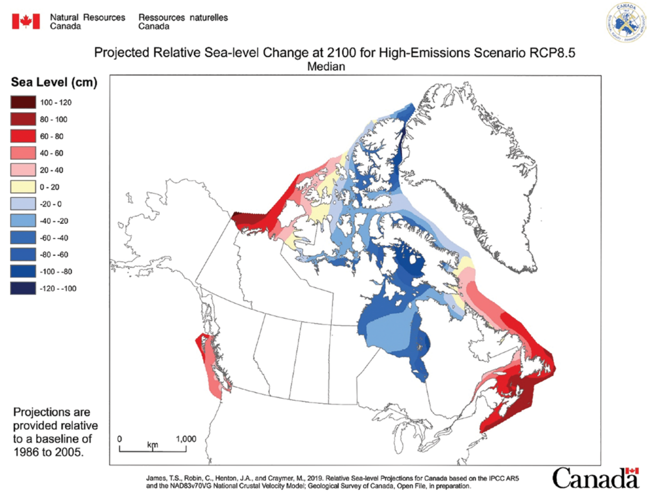


Figure 29. Map of projected relative sea-level change at 2100.

Using an innovative statistical technique, derived national-scale coastal sensitivity indices are part of the recent release of CanCoast, an online national-scale coastal database. Northern coastlines are among the fastest changing areas in the world. NRCan scientists monitor the environmentally sensitive Beaufort Sea region, to gain more knowledge of climate-driven change. Improved knowledge helps decision-makers develop effective adaptation strategies for existing and proposed infrastructure and communities.

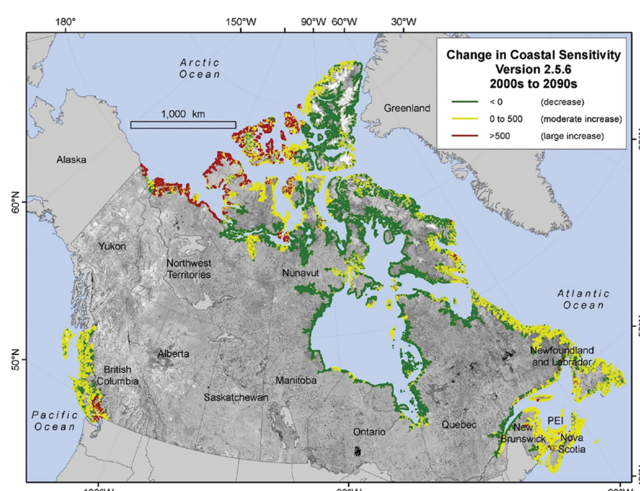


Figure 30. Change in coastal sensitivity.

Extreme Events - Advancing Climate Adaptation through Drought Risk Assessment for the Hydro-power Industry (EE): Geoscience supporting the advancement of climate adaptation using past drought history

All Canadian economic sectors are impacted by climate change, including the energy sector. To assess potential climate change effects on future water regimes, the hydropower industry is using available data to simulate hydroclimatic variability and estimate future drought risks. Unfortunately, existing climatic data cover a very short time period, making forecasts unreliable. To overcome this lack of data, CCGP researchers use isotopic analysis of old trees to reconstruct the hydrological conditions of the last two centuries. The first isotope-based hydroclimate reconstruction from eastern Labrador was recently published. A second field campaign conducted in northern Manitoba is expected to generate improved hydroclimatic reconstructions. A better understanding of the evolution of these water regimes will be used to forecast potential climate change effects, with anticipated benefits for the Canadian hydropower industry.

Glacier Mass Balance (GMB) Project: Measuring Canada's glaciers to enhance understanding of the causes and consequences of the rapidly changing northern environments

As a circumpolar nation, Canada has international commitments to enhance understanding of the causes and consequences of the rapidly changing Arctic environment. Canada has the largest area of glacier ice (~200,000 km^2) after the Greenland and Antarctic ice sheets; ~75% of Canada's glaciers and ice caps are in the Arctic. Monitoring Canada's glaciers is critical to assess global glacier change and to inform decisions on adaptation in the Arctic where change is most rapid. Current research focuses on the development and application of remote-sensing techniques and modelling, to assess broad scale patterns of glacier change. The systematic long-term glacier change observations reveal Canada's glaciers as the third most important contributor to sea-level rise in the northern hemisphere. Research with the University of Alberta and the hamlet of Grise Fiord, Nunavut, will contribute to understanding the impact of enhanced glacier melt on Arctic marine ecosystems, including the Indigenous people they support. A new, first-ever empirical glacier mass balance model for the Canadian Rockies and Southern Interior Ranges, contributes to western Canada water availability studies.

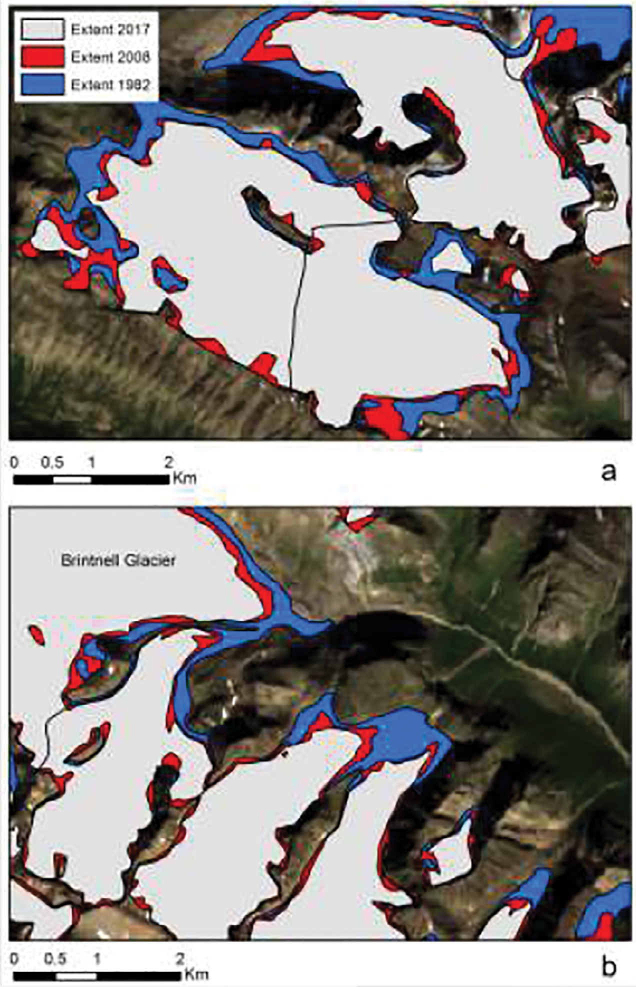


Figure 31. Glacier area changes between 1982-2008 for select glaciated regions in Nahanni National Park and Reserve. Note the evidence of fragmentation and instances where glacier termini no longer coalesce.

CCGP science contributed to National Climate Change Assessment 2019

GSC scientists are on the frontier of understanding the effects of climate change on Canada's sea levels, permafrost and glaciers. Their work contributed to the Environment and Climate Change Canada publication, *Canada's Changing Climate Report 2019* (CCCR 2019) which provides an overview of how and why Canada's climate is changing and the projections for the future. CCGP scientists provided relative sea-level change projections across Canada's coasts, reported on glacial mass balance from field and satellite observations, and gave ground temperatures and the trends in Canada's permafrost regions. The impacts of these changes, such as the expected increase in extreme high water-level events where relative sea level is projected to rise, and the effects on infrastructure where permafrost is warming and thawing, will help inform adaptation decision-making and increase public awareness and understanding of Canada's changing climate.

Strategic Priority 4: Geoscience for Society

Open Geoscience

Open Geoscience (OG) ensures that federal geoscience data and information are accessible, and reusable. It addresses the "how" rather than the "what" of GSC science. An important component of implementing Open Science is to continue to ensure that information systems are in place and maintained to generate, store, manage and disseminate GSC data, publications, collections and knowledge. To assist in this, measures are being implemented to modernize publication management and dissemination tools.

Canadians expect their government to be open, transparent and accountable. They also expect their government to deliver real and meaningful results fairly, efficiently and responsibly. This means that:

- Services are simple and easy to access and use;
- Services are essentially user centric;
- Data is shared and reused where appropriate;
- Services are digitally enabled and seamless.

Canadians accessing and using open information and data generates economic opportunities and increases trust and engagement in government activities.

Recent successes include:

The launch of the Publication Management Tool, a new internal system to manage the flow of GSC's scientific and technical publications including maps and articles in external scientific journals.

Indigenous Engagement

The GSC is active in the field on land and at sea across the country, undertaking geoscientific research to understand Canada's mineral resource endowment, natural hazards, groundwater, energy and changing climate. This work often takes place with and near Indigenous communities, particularly in the North, but also in other areas of Canada. For example, over time the Geo-Mapping for Energy and Minerals Program has conducted fieldwork that has affected and/or taken place close to 65 Indigenous communities.

The GSC engages with Indigenous groups directly in many cases, working with communities to increase our shared understanding of the land, and sometimes through advisory bodies such as the Advisory Group of Northerners (AGN), hunters and trappers organizations and game councils.

- The GSC's Climate Change Geoscience and Public Safety Geoscience Programs are working with the Hamlet of Tuktoyaktuk, Northwest Territories to better educate, communicate and deliver coastal science in a meaningful way to the community.
- The GSC's Public Safety Geoscience Program is working with the Semiahmoo First Nation in southwestern British Columbia to develop a shared knowledge of coastal hazards and create risk reduction strategies to mitigate these hazards.
- GEM returned to many northern communities in 2019-20 to deliver results of previous years' research. Through this, there are opportunities to connect with traditional knowledge and Indigenous perspectives, as per the desires of the communities.
- The GSC's Geoscience for New Energy Supply Program, in collaboration with Parks Canada, incorporated traditional knowledge of the Haida People in a research study that helped to formulate the conceptual model of the thermal system at Hotspring Island in Haida Gwaii, British Columbia and understand the impact of seismic events on deep crustal groundwater flow.
- The GSC's Environmental Geoscience Program has worked with Indigenous groups to effectively include traditional knowledge in their collaborative work. This has resulted in publications co-authored with Indigenous communities, such as Continual change and gradual warming: A summary of the North

Slave Métis Alliance's recorded cultural knowledge on climate and environmental change (2017).
- Based on the experience of the Environmental Geoscience Program, guidance documents and publications for working with traditional knowledge have been developed, including Introduction to Traditional knowledge studies in support of geoscience tools for assessment of metal mining in Northern Canada (Galloway, 2018).

Indigenous reconciliation is explicitly recognized as a key part of the GSC Strategic Plan 2018-2023. The GSC has a history of working with Indigenous communities, particularly in remote parts of the country. With its history, relationships, and reach, the GSC has a huge opportunity to further the reconciliation agenda. In 2019-20, an effort is being undertaken to examine the collaborations and relationships that currently exist and identify what more could be done to work effectively with Indigenous groups to coordinate and support this work and further co-develop projects by using traditional and geoscientific knowledge for land-use planning, management and decision making.

Strategic Priority 5: Our People, Our Science

Science Laboratory Network

The Science Laboratory Network (SLN) provides innovative lab-based research leadership and state-of-the-art analysis and interpretation for all GSC programs and increases effectiveness, connectivity, and efficiency in GSC laboratories.

Recent successes include:

Lab scientists have developed analytical techniques using ColdBlock, a Canadian innovation, a new geochemical technology for digesting solids with faster, more precise and safer results. It has applications throughout all facets of geochemistry and lab-based research projects.

Lab scientists have developed a temperature calibration framework for clumped isotope analyses through precipitation of synthetic calcites. Clumped isotopes provide critical information on the temperature of paleofluid systems and are applicable in a wide range of geological research, including basin analysis, diagenesis, paleoclimate and ore deposit studies.

Lab scientists have developed a straightforward method to differentiate organics associated with oil sands process-affected water (OSPW) from those found naturally in groundwater in contact with the bituminous McMurray Formation. These developments contribute to environmental forensics of organic contaminants in Canada's oil sands region.

Organic geochemistry data have been included in thermodynamic modeling of hydrocarbon compositions in rocks in order to integrate geochemistry with chemical/reservoir engineering for more efficient hydrocarbon extraction.

Workplace well-being

To contribute to the Government of Canada's focus on Mental Health and Workplace Well-being, there are many initiatives being undertaken within the GSC. Each GSC Division has an initiative, and horizontal initiatives also span the organization across Canada. In 2019-20 there were two key horizontal initiatives: The Together for Respect and the Mentorship Matters Initiative.

The Together for Respect (TfR): The TfR Initiative has an eight-point plan for contributing to workplace improvement. Its vision is a culture of respectful relationships across sectors, hierarchies, genders, and nationalities. We are working together towards healthy relationships through mutual respect and civility, enabling well-being and mental health in the workplace. This initiative is an employee-management driven initiative where regular dialogue takes place. TfR objectives include:
- Short Term: Enhanced leadership best practises and increased engagement through a culture of recognition - from a “Thank You” to a Golden Logan Award (the foremost mark of employee or team recognition in the GSC). Logan Awards were initiated in 2017 to mark GSC`s 175th anniversary, and are awarded annually to one person or team per Division.
- Medium Term: Building a better workplace and increasing mental health awareness resulting in increased engagement leading to innovation.
- Long Term: A workplace of healthy relationships through respect and recognition,

ensuring a culturally diverse high performing engaged organization.

Mentorship Matters Initiative: this initiative matches mentors and mentees to form partnerships, to foster learning, personal development and career growth.

GSC Ottawa Working Collection

In 2019-20, the GSC was required to conduct extensive sample triaging and other work in preparation to relocate working collections of rock samples from the Tunney's Pasture Warehouse, GSC Ottawa, to new facilities.

Well over 1 million samples were triaged and either catalogued, or if appropriate, discarded (**Figure 32.**). In tandem with the sample triage, the team has also been heavily involved in the design of the new warehouse facility.

Figure 32. Over 1 million samples were triaged and either catalogued or if appropriate discarded in preparation for moving the contents to a new warehouse facility.

Generation 8 Initiative

The GSC geoscience activities are driven by constantly evolving geographic, economic, social, environmental, and political factors and national needs. Since its inception in 1842, the GSC has had seven main trends (generations) furthering the understanding of the geoscience of Canada with evolving technologies, models and scientific methods. Now in its 8th generation, with a rapid emergence of new digital technologies, the GSC recognizes the need to keep up with new approaches, ideas, clients, staff needs and infrastructure. With input from stakeholders, the Generation 8 Initiative (GEN8) aims to ensure GSC science remains relevant through:

- Increasing science-policy relevance and impact;
- Strategic partnerships/collaborations;
- Meeting targeted user needs;
- Empowering staff (innovation, development & renewal);
- Developing new approaches, methods, ideas;
- Efficient and effective systems and infrastructure; and
- Improving communications – internal and external.

Changing societal needs and technologies transform how we understand and interact with the world. These changes enable the GSC to continually reinvent itself and remain relevant to successive generations of Canadians.

Generation 8 Areas of Focus

Figure 33. The five major compartments of the GEN8 initiative.

Emerging Priorities

New challenges led by evolving federal priorities, such as critical minerals, enhanced federal-provincial/territorial collaborations, and technological innovations require the GSC to continue to evolve. The GSC must adapt to meet demands and expectations from client, stakeholders and partners. Over the last few years, the GSC has taken the first steps to shift toward geoscience digitalization and more collaborative environments.

Digital Innovation

To better respond to rapidly evolving federal science priorities, the GSC is using digital technologies for various predictive geoscience applications. Current policy drivers include:

- The need for new resources (e.g., critical minerals, minerals and metals for a low carbon future);
- The increasing costs of natural hazards (e.g., landslides, climate change);
- Changing technologies which enable visualizing/understanding the world in new ways; and
- The need for geoscience informed science-policy advice.

> The GSC is setting international standards in the adoption of digitization and disruptive technologies in the lands and minerals sector. The GSC has incorporated cutting-edge research trends such as the use of big data, data analytics, augmented reality and machine learning, including artificial intelligence, in many areas such as 3D geological, groundwater, and oil and gas modelling.

Integrating land/space-based geoscience observations and research models with powerful new digital technologies are revolutionising the lands and minerals innovation ecosystem. The interface of earth scene and digital technologies are enabling new or much improved predictive applications, including: neural networks applied to mineral resource estimates, virtual reality applied to 3/4D mapping, geo-hazard risk assessments integrating game theory and human behavior, earthquake early warning systems triggered and operating without human intervention to protect people and infrastructure. Such system-based approaches will likely continue to accelerate and benefit sustainable development. However, success will depend on cooperative, organizational-level approaches to overcome enormous challenges including complex and costly system architectures, the breaking down of disciplinary silos, developing partnerships beyond traditional organizational boundaries, and the need for more deliberate bridging of the gap between research and innovation.

Annexes

Annex I: Geological Survey of Canada Reporting Structure Overview

Natural Resources Canada (NRCan) Departmental Results Framework

NRCan delivers its results through the Departmental Results Framework (DRF) in three core responsibilities: (1) Natural Resource Science and Risk Mitigation; (2) Innovative and Sustainable Natural Resource Development; and (3) Globally Competitive Natural Resource Sectors.

All GSC work falls under the NRCan DRF Core Responsibility 1 (CR-1): *Natural Resource Science and Risk Mitigation.* The objective of CR-1 is to lead foundational science and share expertise for managing Canada's natural resources, reducing the impacts of climate change, and mitigating risks from natural disasters and explosives. The DRF under CR-1 are Canadians have access to leading-edge scientific and technical products on natural resource management that can be used to inform decisions.

Within the DRF, the LMS programs that encompass GSC programs are Geological Knowledge for Canada's Onshore and Offshore Lands, Geoscience for Sustainable Development, and Geoscience for Keeping Canada Safe.

For more information: https://www.nrcan.gc.ca/plans-performance-reports/dp/2019-20/21771

Natural Resources Canada's Lands and Mineral Sector's Performance Information Profiles

NRCan has 11 sectors/offices, one of which is the Lands & Minerals Sector (LMS). LMS has seven branches including the GSC. Aligned with the Department Results Framework, LMS has 11 Performance Information Profiles (PIPs). The PIPs are a management tool for program officials to organize and co-ordinate performance information relevant to programs. The PIPs are evergreen documents that enable the collection of data to support monitoring, routine program and policy decision-making, evaluation, reviews, and other activities for programs. The GSC reports annually on LMS PIPs.

At the LMS program level, GSC science programs report under the following three PIPs:

- Geological Knowledge for Canada's Onshore and Offshore Lands;
- Geoscience for Sustainable Development; and
- Geoscience for Keeping Canada Safe.

1. Geological Knowledge for Canada's Onshore and Offshore Lands

Through this PIP, NRCan produces geoscientific data and knowledge to map the regional geological context of Canada's onshore and offshore lands (*see* logic model in Figure 34). NRCan provides information on new mineral and hydrocarbon potential to support other sectors and departments with strategic resource assessments, methodologies, and data to make evidence-based decisions. NRCan also increases the availability and use of geoscience data assets and knowledge products by developing value-added analyses and tailoring information to broader audiences. NRCan acquired and interpreted geophysical data that was the basis of a formal submission defining the outer limits of the extended continental shelf beyond 200 nautical miles in the Atlantic and Arctic oceans as part of Canada's obligation to the United Nations Convention on the Law of the Sea. International recognition of this new offshore territory will give Canada sovereign rights over the natural resources on the seabed and subsoil.

2. Geoscience for Sustainable Development of Natural Resources

This PIP creates new geoscience knowledge that supports sustainable development of Canada's land, mineral, energy, and water resources (see logic model in Figure 35). Geoscientific knowledge informs land-use decisions such as marine protected areas, pre-exploration geoscience so that companies can efficiently discover new mineral and low-carbon-footprint energy resources, and environmental and groundwater studies so that resource sites can be developed and efficiently remediated post-production. Integrating the results of these studies will increase the efficiency of sustaining mining- and energy-dependent communities, while ensuring that these developments impact the environment and groundwater in the most minimal way. NRCan/LMS provides expert advice to government departments, regulatory bodies, and industry to inform regulatory policies, industry practices, and environmental assessments that contribute to sustainable land-use decision-making and groundwater management. This ultimately serves to improve Canada's global competitiveness and supports the sustainable development of Canadian mining-dependent communities.

3. Geoscience for Keeping Canada Safe

This program undertakes the monitoring of, research into, and effective planning against various natural and human-induced hazards including earthquakes, tsunamis, landslides, and impacts related to climate change, geomagnetic storms, radiological and nuclear incidents (*see* logic model in Figure 36). Through the provision of hazard information, NRCan helps other levels of government, including international government bodies, the private sector, and professional organizations, to prevent, mitigate, prepare for, respond to, and recover from natural disasters. Similarly, stakeholders use geoscience information to minimize the risks that climate change poses to communities and infrastructure in vulnerable areas.

Figure 34. Logic model used for the Geological Knowledge for Canada's Onshore and Offshore Lands Performance Information Profile.

ULTIMATE OUTCOME
Effective management and development of Canada's sovereign lands and natural resources

↑

INTERMEDIATE OUTCOME	
International recognition of Canada's outer limits of the extended continental shelf (ECS) in the Atlantic and Arctic oceans	Indigenous communities/stakeholders use thematic geoscience knowledge for land use decision making

↑

IMMEDIATE OUTCOME	
Delineated outer limits of the ECS beyond 200 nautical miles in the Atlantic and the Arctic oceans	Indigenous communities/stakeholders access geoscience knowledge for Canada's onshore and offshore lands

↑

OUTPUTS	
Geoscience Data and Knowledge • Data products • Scientific publications • Geoscience knowledge presentations	Engagement and Collaboration • Workshops • Collaboration agreements • Engagement sessions • Communications products • International science diplomacy

↑

ACTIVITIES	
United Nations Convention on the Law of the Sea (UNCLOS) Program • Present Canada's Atlantic Ocean submission to CLCS • Define Arctic ECS outer limits • Finalize scientific publications to strengthen Canada's scientific case for the outer limits of its ECS • Prepare Canada's Arctic Ocean submission	Geo-mapping for Energy and Minerals (GEM) • Enable multi-jurisdictional collaborations • Actively disseminate new geoscience data and knowledge • Collect, acquire, and analyze data • Engage Indigenous communities/ stakeholders in ongoing dialogue • Collaborate with Indigenous communities/stakeholders to integrate geoscience knowledge in land-use decision-making

Figure 35. Logic model used for the Geoscience for Sustainable Development of Natural Resources Performance Information Profile.

ULTIMATE OUTCOME
Canada is a world leader in the sustainable development of natural resources

↑

INTERMEDIATE OUTCOME		
Geoscience knowledge informs policy-making and/or advances natural-resources research	Natural-resources industry adopts development and extraction practices with low environmental impacts	Natural-resources industry adopts innovative approaches for detection and delineation of natural resources

↑

IMMEDIATE OUTCOME		
SGeoscience knowledge is accessible for environmental stewardship	Natural-resources industry and stakeholders are aware of the latest sustainable development research findings	Natural resources industry and stakeholders are aware of the latest exploration knowledge, data and detection techniques

↑

OUTPUTS	
Engagement and Collaboration • Workshops • Collaborative agreements • Indigenous engagement	Geoscience Data and Knowledge • Scientific reports, publications, tools and analytical methods • Geoscience knowledge presentations

↑

ACTIVITIES	
• Provide expert geoscientific reviews of resource-development projects via the Canadian Environmental Assessment Act process	• Deliver resource assessments in support of Canada's commitment to conserve 10% of its marine areas by 2020
• Distinguish between the environmental effects of natural-resource development and those produced by natural processes	• Conduct geoscience for new energy supply, advance the understanding of new energy sources, and/or explore frontier regions
• Characterize large aquifer systems; integrate and disseminate hydrogeological information	• Undertake geoscience studies of ore-forming processes • Improve and develop methodologies that target detection of buried mineral deposits

Figure 36. Logic model used for the Geoscience for Keeping Canada Safe Performance Information Profile.

ULTIMATE OUTCOME
Canada is more resilient to natural hazards

INTERMEDIATE OUTCOME	
Federal, provincial, territorial and Indigenous decision-makers make science-based decisions related to climate change adaptation and disaster risk reduction	Emergency management operations and decision-making are more effective

IMMEDIATE OUTCOME		
Stakeholders are aware of, value and use NRCan geoscience data, knowledge and tools related to climate change adaptation	Stakeholders are aware of, value and use NRCan geoscience data, knowledge and tools related to disaster risk reduction	Emergency managers find value in NRCan monitoring and alerting information and decision support products

OUTPUTS	
Geoscience knowledge products • Data and datasets • Tools • Maps • Scientific reports and publications	• Real-time 24/7 natural hazard monitoring and alerts • Information products to support emergency management decision-making • Nuclear and radiological analysis and forensics

ACTIVITIES		
Climate Change Geoscience (CCG) • Supporting adaptation in permafrost areas • Supporting adaptation in coastal areas • Advancing efforts to protect from floods • Understanding changes to Canada's glaciers	Public Safety Geoscience (PSG) • Earthquake hazard research • Space weather research • Terrestrial and marine landslide research • Risk assessment case studies and tools development	Canadian Hazards Information Service (CHIS) • 24/7 monitoring and altering for natural hazards in Canada • Providing near-real-time information products to support emergency management decision making • Responding to nuclear and radiological incidents

GSC Strategic Priorities

The GSC provides Canada with a comprehensive geoscience knowledge base contributing to economic development, public safety, and environmental protection by acquiring, interpreting, and disseminating geoscience information concerning Canada's landmass, including the offshore. Through its programs and activities, the GSC engages with Indigenous communities, incorporates traditional knowledge with western science, and supports decision-making by communities.

To guide its programs and activities, the GSC's Strategic Plan identifies the key priorities for 2018 to 2023 and related goals to support their implementation (Table 4). Priorities one to three outline the key scientific contributions to NRCan's strategic priorities by producing new geoscience knowledge and are aligned with DRF and LMS PIP priorities. Priorities 4 and 5 describe organizational and business objectives to sustain capacity and foster a healthy work environment that is required to conduct efficient, effective, and relevant work. Table 5 presents the directors and program manager associated with each item.

Table 4. Geological Survey of Canada 2018-2023 Strategic Priorities

Strategic Priority	Strategic Priority (SP) goals
Strategic Priority 1: Geological knowledge for Canada's Onshore and Offshore Lands	SP-1-1: When the GEM-2 program ends in 2020, we will publish new knowledge of Canada's geology in frontier areas of Arctic onshore and offshore lands. The knowledge will supply critical information to decision-makers to ensure that future management of lands and resources in the North is guided by scientific evidence.
	SP-1-2: Through our contribution to the completion of Canada's UNCLOS submission for the Arctic in 2019, we will have completed the delineation of the outer limits of Canada's extended continental shelf, thus fostering international recognition of Canada's last frontier.
	SP-1-3: We will implement new programs, including a program to respond to the Arctic Policy Framework, as well as tools and methods to discover, model, visualize, and interpret the 3D geology of Canada's lands. In both onshore and offshore domains, we will integrate traditional mapping of the land surface and seabed with geophysical-survey and observatory data from below ground. This work will help us to develop 3D models of Canada's geological framework and a deeper understanding of Earth processes.
Strategic Priority 2: Geoscience for Sustainable Development	SP-2-1: We will develop new mineral deposit models through research on how geological processes in ore-generating systems evolve through time. We will also support technological innovation within the exploration industry, with the combined aim of stimulating the discovery of new subsurface deposits.
	SP-2-2: We will advance research to combine knowledge of groundwater aquifers and their links with surface water systems to build integrated models of water systems for sound, comprehensive water management by the provinces and territories.
	SP-2-3: We will continue to deliver authoritative geoscience, including research on cumulative effects, to support land-use planning and environmentally sound resource development, both on land and in our coastal and offshore waters.
	SP-2-4: To facilitate development of low-carbon energy sources, we will support the fledgling geothermal industry and other renewable energy industries to assess resource potential, enhance energy recoverability, and support environmental assessments.
	SP-2-5: We will develop methodology to better characterize shale-hosted resources and transfer knowledge to industry, regulators, and other stakeholders.

Strategic Priority 3: Geoscience for Keeping Canada Safe	SP-3-1: We will develop advanced hazard models for earthquakes, tsunamis, landslides, and space weather to support regular updates of building codes and emergency planning.
	SP-3-2: We will assess the impacts of climate change on the water cycle, permafrost, and coastal erosion and inundation to enable planning of resilient communities and infrastructure.
	SP-3-3: We will continue to work with the Canadian Hazard Information Service and Ocean Networks Canada to build an earthquake early-warning system for southern British Columbia.
	SP-3-4: We will integrate our geoscience with socioeconomic analysis and engineering data to provide a comprehensive understanding of risk from natural hazards and climate change to critical infrastructure and urban centres.
	SP-3-5: We will focus on transferring this knowledge of hazards and risk to a wide range of stakeholders, including the provinces and territories, professional associations, and the insurance industry, to support actions that will decrease Canada’s exposure to natural disaster and climate change.

Strategic Priority 4: Geoscience for Society	SP-4-1: We will establish a governance structure to manage geoscience information through best practices and processes based on recognized standards. Through this approach, we will document, store and manage the GSC's data. We will ensure that we have a robust and modern data infrastructure that will ensure sustainability and will work effectively with external tools such as the Federal Geospatial Platform and the open data initiative. The infrastructure will also facilitate the discovery and dissemination of our data.
	SP-4-2: In the spirit of Canada's open science initiative, we will establish a modern publication process that incorporates open science principles and is responsive to client needs. We will work with provincial and territorial surveys to synthesize Canada's geoscience knowledge and data and develop open and dynamic web portals to share geoscientific information.
	SP-4-3: We will develop an approach to land-use planning that is informed by geoscience by initiating dialogue and building relationships with federal, provincial, and territorial counterparts, Indigenous groups, and non-governmental professional organizations. Through pilot projects, we will build a methodological framework for providing accessible multidisciplinary geoscience to inform land-use planning.
	SP-4-4: We will build on past engagement to facilitate and guide our relationships with Indigenous communities based on recognition of traditional knowledge, respect, and co-operation. Based on needs identified by Indigenous communities, we will put special emphasis on working with several of those communities to co-develop prototype projects by using traditional and geoscientific knowledge for land-use planning, management, and decision-making. With provinces, territories, universities, and professional associations, we will investigate ways to build geoscience capacity within Indigenous communities to enhance incorporating geoscience knowledge into land-management decision-making by communities.

Strategic Priority 5: Our People, Our Science	SP-5-1: We will proactively support and develop a resilient, high-performing and diverse workforce skilled in emerging and traditional areas of geoscience research by encouraging cutting-edge skill sets and continuous learning. We will modernize our workforce and acknowledge the continued efforts of our staff to advance public geoscience in Canada.
	SP-5-2: We will foster a modern work environment that balances sound scientific infrastructure and a healthy workplace; offers world-class laboratories, collections, and facilities; and provides opportunities for employees to contribute meaningfully to the development of Canada.
	SP-5-3: We will lead and advance the geoscience research agenda in Canada and internationally by advancing a scientific research agenda that demonstrates scientific and technical leadership, challenges paradigms, and makes a difference to Canadian society.
	SP-5-4: We will serve as the hub of geoscience research in Canada through collaboration with other federal departments, other levels of government, universities, the private sector and international research institutes.

GSC 2019-20 science programs/services, projects and activities

Table 5. Directory of the GSC 2019-2020 Science Programs/Services, Projects and Activities

Strategic Priority Board	GSC Program / Director / Service & Program Manager	Projects & Project Leader	Activities & Activity Leader
SP-1	Geo-mapping for Energy and Minerals (GEM) Program Linda Richard Michel Plouffe	Baffin Natalie Shea	North Baffin – Bedrock Mapping Natalie Shea
			Cretaceous Stratigraphy – Northern Baffin Bay Jim Haggart
			Baffin Region Synthesis Nikole Bingham - Kozlowski and Lynn Dafoe
		Cordillera Steve Irwin	Crustal Structure of Southeast Yukon Jim Ryan
			Stikinia Bedrock Alex Zagoreski
			Yukon Tectonic Evolution - Late Mesozoic to Tertiary Dawn Kellett
		Hudson-Ungava Danny Wright	Saglek Block – Geological Evolution and Mineral Potential David Corrigan
			Geophysics - Southampton and Kaskattama Highlands Jim Craven
		Mackenzie Carl Ozyer	Mackenzie - Selwyn Geo-Transect Robert McNaughton and Karen Fallas
			Southern Mackenzie Surficial Mapping Roger Paulen and Rob Smith
			North Bear Surficial Mapping Dan Kerr
		Rae Genevieve Marquis	Rae – Synthesis of Glacial History – Keewatin Sector Isabelle McMartin
			Boothia – Somerset – Integrated Geoscience Mary Sanborn - Barrie
		Western Arctic Carl Ozyer	Smoking Hills – Stratigraphy and Paleotology Rob Smith and Jennifer Galloway

Strategic Priority Board	GSC Program / Director / Service & Program Manager	Projects & Project Leader	Activities & Activity Leader
SP-1	United Nations Convention on the Law of the Sea (UNCLOS) Program Mary-Lynn Dickson	Arctic Ocean submission Mary-Lynn Dickson	Geomorphology David Mosher and Kai Boggild
			Seismic reflection John Shimeld
			Seismic refraction Ruth Jackson
			Potential fields and geological samples Gordon Oakey
			Geological samples (Alpha Ridge) Marie-Claude Williamson
			Geochronology Dawn Kellett
			GIS and Database Management Walta-Anne Rainey
	Canada in 3D (C3D) Linda Richard Nicole Couture	Canada in 3D Boyan Brodaric	
SP-2	Impact Assessment (IA) Service Linda Richard Danny Wright	GSC IA Service Danny Wright Aruna Dixit	*List of projects 2019-2020 YU: Coffee NU: Whaletail Expansion, Mary River, In-pit Tailings Meadowbank BC: Kitimat LNG Expansion, Roberts Bank T2, Wespac Tilbury, Cedar LNG, Michel Coal, TMX AB: Springbank, Base Metal SK: Rook 1 ON: Victoria, Goliath, Bending Lake, Reid River Rd, MMR, Marten Falls, Webequie Rd Rof, NSDF, Milton Hub QC: Energie Saguenay, Montreal LRT, Gazoduq, Contracoeur, Rose Tantalum, James Bay Lithium, Beauport NLL: Mar. Ter, Central Ridge, West Flemish Pass, BHP Exploration, Bay du Nord, Valentine Gold, Deep Port-Laurentia, Husky, Orphan Basin NS: 15 Mile Stream, Grassy Mtn Coal, Beaver Dam, St. Lawrence Fluorspar

Strategic Priority Board	GSC Program / Director / Service & Program Manager	Projects & Project Leader	Activities & Activity Leader
SP-2	Environmental Geoscience Program (EGP) Andrée Bolduc Gilles Cotteret	Induced Seismicity Research Honn Kao	
		Source Determination Using Isotope Ratios Characterization of Environmental Samples (SOURCES) Paul Gammon	
		Measuring, Monitoring And Verification of Geological Carbon Storage Don White	
		Science-based Dredge Disposal Guidelines For Port Expansion Gwyn Lintern	
		Cumulative Effects in Cobalt Watersheds Alexandre Desbarats	
		Environmental Impacts of Permafrost Thaw in the Arctic Mathieu Duchesne	Impacts of Permafrost Degradation Mathieu Duchesne
			Permafrost Contaminant Geochemistry Paul Gammon
		Evaluating Potential Impacts of Oil And Gas Development Activities, Including Induced Seismicity On Non-Saline Aquifers In The Fox Creek Area (Alberta) Christine Rivard	
		Geoscientific Research into Accidentally Spilled Petroleum (GRASP) Jason Ahad	Marine Oil Spill Studies (MOSS) Manuel Bringué
			Environmental Impact of Diluted Bitumen (Dilbit) Jason Ahad

Strategic Priority Board	GSC Program / Director / Service & Program Manager	Projects & Project Leader	Activities & Activity Leader
SP-2	Environmental Geoscience Program (EGP) Andrée Bolduc Gilles Cotteret	Long-term Hydrological Dynamics of Canada's Largest Watershed: Climate Controls On Water Quantity of the Mackenzie River Basin Jennifer Galloway	
		Volcanoes Role In The Global Mercury Budget Peter Outridge	
	Groundwater Geoscience Program (GGP) Andrée Bolduc Yves Michaud	Archetypal Aquifers in Canada Hazen Russell	Aquifers Classification Hazen Russell
			Archetypal Aquifers Case Studies Hazen Russell
			South Nation Aquifers Modelling Hazen Russell
			Borehole Calibration Facilities in Bells Corners Heather Crow
			Principal Bedrock Aquifers Map In Canada Alfonso Rivera
			eBook Contribution Alfonso Rivera
		Groundwater Information Network Boyan Brodaric	Groundwater Information Network (GIN) portal and database Éric Boisvert
			Permafrost Information Network (PIN) Héryk Julien
			Dashboard Development François Létourneau
			Standards Development Boyan Brodaric
			Linked Data Boyan Brodaric

Strategic Priority Board	GSC Program / Director / Service & Program Manager	Projects & Project Leader	Activities & Activity Leader
SP-2	Groundwater Geoscience Program (GGP) Andrée Bolduc Yves Michaud	Water Resources Characterization And Modelling Daniel Paradis	Southern Quebec GW modeling Daniel Paradis
			Wells4GRACE John Crowley
			Hydrogeophysics Daniel Paradis
			Glaciers and Rockies Regional Groundwater Flow System Alfonso Rivera
		Fox Creek Aquifers System Christine Rivard	SW/GW Flow Dynamics Christine Rivard
	Targeted Geoscience Initiative Program (TGI) Geneviève Marquis (Director and Program Manager)	Gold Patrick Mercier-Langevin	System Controls on Gold Through Space and Time (Source to Trap) Patrick Mercier-Langevin
			Tectonic Influences on Gold (Tectonic Drivers and Conduits) Patrick Mercier-Langevin
		Nickel-Copper-Platinum Group Elements Systems Wouter Bleeker	System-Scale and Deposit-Scale Controls on Nickel-Copper-Platinum Group Elements Mineralization in Cratonic Areas and Their Margins Wouter Bleeker
			Magmatic Architecture of Cr-bearing Ore Systems Wouter Bleeker
		Porphyry-Style Mineral Systems Neil Rogers	Arc-related Porphyry Mineralization in Space and Time Neil Rogers
			Mineral Markers of Porphyry Processes Neil Rogers
			Post-Orogenic Porphyry Systems In Space And Time Neil Rogers
		Uranium-Rich Ore Systems Eric Potter	Uranium Fluid Pathways Eric Potter

Strategic Priority Board	GSC Program / Director / Service & Program Manager	Projects & Project Leader	Activities & Activity Leader
SP-2	Targeted Geoscience Initiative Program (TGI) Geneviève Marquis	Volcanic- and Sedimentary-Hosted Base Metal Mineralization (SEDEX-VMS) Jan Peter	Seafloor Ore Deposition through Space and Time Jan Peter
			Base Metal Sources and Mineralizing Processes Jan Peter
	Geoscience for New Energy Supply Program (GNES) Sonya Dehler Edward Little	Laboratory Method Development Dennis Jiang	Characterization of Hydraulic Fracturing Flowback and Produced Water: Understanding Its Environmental Impacts and Improving Operations and Production Efficiency Dennis Jiang
			Adsorbed and Free Oil in Unconventional Shale Reservoirs using NMR T1-T2 maps Dennis Jiang
		Decreasing Environmental Risk Omid Ardakani	Economic and Environmental Impact Concerns of Hydrogen Sulfide (H2S): Understanding Source And Formation Mechanism(S) in the Montney Formation Omid Ardakani
			Enhanced CO2 Utilization in Tight Oil and Unconventional Gas (TOUG) Reservoirs Omid Ardakani & Zhuoheng Chen
		Pore Fluid Implications Zhuoheng Chen	Using Big Data and AI to Identify New Environmentally Sustainable Pathways for the Production Unconventional Transitional Energy Resources Zhuoheng Chen
			Algorithm and AI Assisted Geologic Feature Characterization Jon Liu & Zhuoheng Chen
		Geothermal-St. Lawrence Lowlands Christine Rivard	Geothermal Heat Production Assessment Through the Use of Deep Hydrocarbon Wells in the St. Lawrence Platform, Québec Christine Rivard

Strategic Priority Board	GSC Program / Director / Service & Program Manager	Projects & Project Leader	Activities & Activity Leader
SP-2	Geoscience for New Energy Supply Program (GNES) Sonya Dehler Edward Little	Regional Geothermal Energy Steve Grasby	Reducing Exploration Risk For Geothermal Resources in Canada Steve Grasby
		Hybrid Geothermal Energy Zhuoheng Chen	Transforming Tight Unconventional Gas (TUG) Resources into Renewable Geothermal Energy: A Feasibility Study within the Western Canada Sedimentary Basin Zhuoheng Chen
		Garibaldi Range Geothermal Energy Steve Grasby	Mount Meager Geothermal Geoscience Steve Grasby
	Marine Conservation Targets Program (MCT) Sonya Dehler Gary Sonnichsen		
	Marine Geoscience for Marine Spatial Planning Program (MGMSP) Stephen Locke (Director and program manager)	Bay of Fundy-Scotian Shelf Brian Todd	Scotian Shelf Bioregion: Seabed Mapping, Benthic Habitat Assessment, Analysis of Seafloor Geologic Processes Vladimir Kostylev
		Newfoundland and Labrador Shelves Vladimir Kostylev	Newfoundland and Labrador Bioregion: Seabed Mapping, Benthic Habitat Assessment, Analysis of Seafloor Geologic Processes Vladimir Kostylev
		Pacific North Coast Kim Conway	Pacific North Coast Bioregion: Seabed Mapping, Benthic Habitat Assessment, Analysis of Seafloor Geologic Processes Vladimir Kostylev
		Salish Sea Randy Enkin	Salish Sea Bioregion: Seabed Mapping, Benthic Habitat Assessment, Analysis of Seafloor Geologic Processes Vladimir Kostylev
		AUV Pilot Project Alex Normadeau	Acquisition And Operation of New Autonomous Seabed Mapping Instrumentation Alex Normadeau
		Data Management IM/IT Sheila Hynes	Design and Delivery of Geospatial Seabed Geoscience Layers for Marine Spatial Planning Sheila Hynes

Strategic Priority Board	GSC Program / Director / Service & Program Manager	Projects & Project Leader	Activities & Activity Leader
SP-3	Climate Change Geoscience Program (CCGP) Stephen Locke Catherine Ste-Marie	Supporting Adaptation in Permafrost Regions Sharon Smith	Improving the Canadian Permafrost Map Sharon Smith
			Transportation Resilience in the Arctic Informed by Landscape Systems Peter Morse
		Supporting Adaptation in Coastal Regions Thomas James	Sea-level Projections for Canada Tom James
			Coastal Dynamics Dustin Whalen
			CanCoast Indices: Validation, Refinement and Application of Coastal Sensitivity and Vulnerability Indices Gavin Manson
			Coastal Infrastructure Threats from Storm Surge in Nova Scotia Vladimir Kostylev
			Predictive Modeling of Future Change on Sable Island, Nova Scotia Vladimir Kostylev
		Extreme Events: Forecasting for Hudson Bay Lowlands and Drought Risk Assessment for the Hydro-power Industry Christian Bégin	Advancing Climate Adaptation Through Improved Flood Forecasting for Hudson Bay Lowlands Hazen Russell
			Improving Drought Risk Assessment Associated With Climate Change For the Hydro-Power Industry of Central and Eastern Canada Christian Bégin
		National Glaciology Project David Burgess	High Arctic David Burgess
			Western Cordillera Mark Ednie
	Public Safety Geoscience Program (PSG) Sonia Talwar Adrienne Jones	Earthquake Geohazards John Cassidy	Intraplate Earthquakes Greg Brooks
			Plate Boundary Earthquakes Joe Henton

Strategic Priority Board	GSC Program / Director / Service & Program Manager	Projects & Project Leader	Activities & Activity Leader
SP-3	Public Safety Geoscience (PSG) Sonia Talwaar & Adrienne Jones	Earthquake Geohazards John Cassidy	Volcanic Hazard Assessment Melanie Kelman
		Landslides and Marine Geohazards Andrée Blais-Stevens	Baffin Bay and Arctic Channels Robbie Bennet
			Beaufort Sea Ned King
			Terrestrial Landslides David Huntley
			Submarine Landslides and Tsunami Hazard Gwyn Lintern
		Space Weather Hazards David Boteler	Ground Effects David Boteler
			Ionospheric Effects Robyn Fiori
			Satellite Effects Larisa Trichtchenko
			Forecast Development Ljubomir Nikolic
		National-Scale Geohazard Risk Assessment Nicky Hastings	CSSP Coastal Flood Mitigation Nicky Hastings
			CSSP Disaster Risk Reduction Pathways Murray Journeay
			Interactive Web Application - ER2 Risk Tool Michel Parent
			Emergency Management Strategy - Earthquake Risk Assessment Malaika Ulmi
SP-4	Open Geoscience (OG) Linda Richard Nicole Couture	IT Infrastructure Khalil Hayek / Mathieu Ouellet	
		Information Systems and Data Kathleen Lauzière / Kyler Coutts	

Strategic Priority Board	GSC Program / Director / Service & Program Manager	Projects & Project Leader	Activities & Activity Leader
SP-4	Open Geoscience (OG) Linda Richard Nicole Couture	Open Access and Public Engagement Kathryn Coyle	
		Synthesis and Integration Boyan Brodaric	
		Earth Material Collections Rhian Evans	
SP-5	Science Laboratory Network (SLN) Genevieve Marquis Vicki McNicoll	Inorganic Geochemistry Research Lab Group Paul Gammon	Environmental and Surficial Lab Facility Paul Gammon
			Analytical Chemistry Lab Facility Simon Jackson
			Marine Geochemistry Lab Facility Michael Parsons
		Paleontology Lab Group Manuel Bringué and Sofie Gouwy	Palynology Lab Manuel Bringue and Jennifer Galloway
			Conodont Lab Sofie Gouwy
			Macrofossil Lab Facility Jim Haggart
		Mineralogy and Physical Properties Group Jeanne Percival	Marine Core and Sedimentology Lab Facility Alexandre Normandeau
			Sedimentology Lab Facility Shauna Madore
			Mineralogy Lab Facility Jeanne Percival
			Paleomagnetism & Petrophysics Lab Facility Randy Enkin
		Isotope Geochemistry and Geochronology Group Bill Davis	Isotopic Geochemistry & Geochronology Lab Facility Bill Davis
			Delta Lab (Stable Isotope) Facility Martine Savard and Jason Ahad
		Organic Geochemistry and Petrology Group Dennis Jiang and Rachel Robinson	Organic Geochemistry and Petrology Lab Facility Dennis Jiang and Rachel Robinson
		GSC Qué lab, INRS Kathleen Lauzière	

Annex II: GSC Program Summaries

This section presents a high-level summary of each of the 14 programs and services of the GSC, their logic models, and highlights of their activities in the 2019–2020 year.

Geological Survey of Canada

Who Are We?

The Geological Survey of Canada's (GSC) is Canada's national geological survey.

► **MISSION**
"Provide authoritative geoscience knowledge to inform the stewardship of Canada's onshore and offshore lands, to sustain responsible resource development for future generations and to keep Canadians safe from natural hazards and related risks"

► **MANDATE**
"Make a full and scientific examination and survey of the geological structure and mineralogy of Canada"

The GSC studies Canada's vast onshore and offshore lands to improve scientific understanding of the dynamic processes that shape the world around us, from mountaintop to seafloor. We bring this foundational knowledge to our partnerships with experts in other disciplines to tackle some of Canada's

21st-century challenges, including searching for deeply buried resources, better understanding climate change and natural hazards and their impacts, and studying the effects of natural resources development on groundwater, air and soil.

- 400 staff in seven centres across Canada
- >30 specialized science laboratories

► COOPERATING ACROSS CANADA
Since 1996, the ***Intergovernmental Geoscience Accord*** provides a framework for cooperation and collaboration among the federal, provincial and territorial geological surveys.

GSC Science Supports

► **Canada's economy**
Public geoscience increases exploration activity by reducing the costs and risks of private exploration. For example for mining...

► **Science-based decision-making**
Public geoscience reduces the environmental risks of regional planning, resource development, informs environmental assessments and supports international negotiations.

► **Informed development of standards**
Public geoscience informs national building and transportation infrastructure codes to make the built environment more resilient.

Geological Knowledge of Canada's Onshore and Offshore Land

GEO-MAPPING FOR ENERGY AND MINERALS
Collaborative initiative (2008-2020) to provide the public, including natural resources industries with modern geoscience knowledge needed to promote exploration and long-term economic development for the vast and untapped resources of Canada's North. This includes development of advanced methods for 3D geological modelling and visualization.

UNITED NATIONS CONVENTION ON THE LAW OF THE SEA
Marine geoscientists have played a key role to meet Canada's obligation under the United Nations Convention on the Law of the Sea to define our continental shelf, beyond 200 nautical miles, in the Atlantic Ocean and Arctic Ocean using robust scientific data and knowledge.

Geoscience For Society

OPEN GEOSCIENCE
Ensuring that federal geoscience data and information are findable, accessible, interoperable, and reusable. Open Geoscience addresses the how rather than the what of GSC science. It aims at fostering further collaborations and increasing the impact of GSC science.

Canada

Geoscience for Sustainable Development

TARGETED GEOSCIENCE INITIATIVE
Collaborative federal geoscience program that seeks to understand the processes that formed Canada's mineral deposits and identify and quantify the key indicators needed to explore for them. Discovery of new deposits and mining districts supports an industry that contributes to the well-being of all Canadians, their communities and our economy.

GROUNDWATER GEOSCIENCE PROGRAM
Improving understanding of groundwater distribution, quantity, flow dynamics and possible impacts on Canada's sustainable development.

ENVIRONMENTAL GEOSCIENCE
Seeks to distinguish the environmental effects of natural resource development from those occurring naturally and to develop new methodologies in geoscience supporting the sustainable development of Canada's natural resources.

IMPACT ASSESSMENT SERVICE
Supporting land-use planning and environmentally sound resource development, both on land and in our coastal and offshore waters. The GSC is the lead agency for evaluating geoscience in environmental impact statements.

MARINE GEOSCIENCE FOR MARINE SPATIAL PLANNING
Development of new maps and analyses of seafloor geology and active seabed processes to inform evidence-based marine spatial planning and regional environmental assessment.

MARINE CONSERVATION TARGETS
Providing estimates of offshore energy and mineral potential to inform decisions related to Canada's current and future targets related to protection of its coastal and marine areas.

GEOSCIENCE FOR NEW ENERGY SUPPLY
Supporting strategies for our transition to a future low-carbon economy through clean energy research and development and the promotion of non- and low-emitting energy resources. This will be done by using advancing the fundamental understanding of Canada's sub-surface landmasses.

Geoscience for Keeping Canada Safe

PUBLIC SAFETY GEOSCIENCE
Developing new and innovative knowledge and tools to support decisions that increase resilience and decrease risk to keep Canadians safe from earthquakes, terrestrial and submarine landslides, volcanoes, tsunamis, and space weather.

CLIMATE CHANGE GEOSCIENCE
To better understand the geological impacts of climate change in Canada for land-use planning and government regulation to help at-risk communities to adapt.

Our People, Our Science

SCIENCE LABORATORY NETWORK
Providing innovative lab-based research leadership and state-of-the-art analysis for all GSC programs, and increasing effectiveness, connectivity, and efficiency in GSC labs

TALENT MANAGEMENT
Fostering a research environment conducive to world-class science by supporting and developing a resilient, high-performing and diverse workforce at the cutting edge of technology and skilled in emerging and traditional areas of geoscience while encouraging continuous learning and development.

Natural Resources Canada | Ressources naturelles Canada

Geo-Mapping for Energy and Minerals (GEM)

GSC STRATEGIC PRIORITY 1: GEOLOGICAL KNOWLEDGE OF CANADA'S ONSHORE AND OFFSHORE LANDS

Why? Collaborative initiative (2008-2020) that provides the public, including natural resources industries, with modern geoscience knowledge needed to promote exploration and long-term economic development for the vast and untapped resources of Canada's North.




Region	Objective	Highlights & Successes
Mackenzie	A lack of geologic knowledge has been a significant detriment to the economic development across the Mackenzie region. Taken the proven oil and gas potential of the region to the next level and discovering new economic mineral resources require improvements in our understanding of the stratigraphic and structural relationships across key regional features.	**Permafrost In the NWT** • Surficial mapping in the Great Slave Region and glacial sediment mapping in thaw-sensitive terrain, identified extremely useful information for land-use planning, infrastructure and resource development. • The Northwest Territory Department of Transport used GEM surficial geological data to help plan the route of the Tlicho All-Season Road, an estimated $150 million project. In turn it might create mining opportunities, such as the $600 million dollar NICO mine targeting gold, copper, bismuth and cobalt, still in planning stage. **Copper Potential in Mackenzie** • Fieldwork identified two geological units previously unknown in the region, potentially extending areas with known copper mineralization potential. This work will complete the first regional effort to place the region into a modern framework and allow Northerners and industry to responsibly develop mineral resources to maximize their socio-economic benefits. **Defining the Darnley Bay Anomaly** • GEM research helped to define the nature, size and depth of the Darnley Bay anomaly – the largest gravity and magnetic anomaly in North America, potentially expanding the resource considerations for nickel, copper and platinum group, as claimed by Darnley Bay Resources Ltd. (now, Pine Point Mining). This work supported their decision to extend their exploration permits in the region until 2023. **Southern Mackenzie Surficial Mapping** • Ice stream research in the area received excellent feedback from international peers at INQUA, and the NWT Geological Survey expressed a very high level interest in our early results and are anticipating additional results which could impact their future field programs. **World's Oldest Fungus Fossils Found in the Northwest Territories** • A routine sample collection led to a unique discovery in the evolution of life on Earth. Microfossils of fungi roughly 1,000-900 million years old were revealed in rock samples from the western Canadian Arctic, marking the earliest known occurrence of fungi. This discovery helps refine the evolutionary tree of complex organisms in the history of life on Earth. • The story was picked up by major newspapers around the world including the New York Times and the Guardian. It was a front page story in the Globe and Mail, a feature article in Cottage Life magazine, and CBC Quirks and Quarks interviewed Elizabeth Turner, one of the collaborators. **Multiple Metals - Great Bear Region** • In July 2019, Fortune Minerals announced the discovery of a new copper mineralization potential at their NICO Project, building on GEM -1 collaborations and data from the Great Bear Region project.

Geo-Mapping for Energy and Minerals (GEM)

GSC STRATEGIC PRIORITY 1: GEOLOGICAL KNOWLEDGE OF CANADA'S ONSHORE AND OFFSHORE LANDS

Region	Objective	Highlights & Successes
Rae	The Rae region is a large, remote, part of the Canadian Shield, west of Hudson Bay, with a complex geological history. It hosts several mines and numerous nickel, uranium and diamond prospects. While perceived to have additional mineral potential, geological knowledge is lacking presenting significant exploration challenges. GEM work aims to better understand the geology and glaciation patterns of the Rae region and how it can enhance mineral exploration.	See below

Glacial Synthesis

- The integration of large volumes of ground-based and remote surface geology and age dating helped piece together the glacial history of the region, providing new knowledge essential for geochemical and heavy mineral surveys.

Integrated Geoscience along the Northwest Passage

- GEM discovered unique differences underlying the Boothia Peninsula indicating that mineral exploration strategies used in other Rae areas are likely inappropriate for Boothia Peninsula.
- This research provided relevant data and knowledge for this isolated region of Nunavut regarding resources assessment and economic development opportunities associated with potentially dramatic increases in shipping due to climate change impacts.

Mineral Potential of the Chantrey-Thelon Area

- Fieldwork identified three main areas with economic potential in three different geological domains: newly recognized copper-nickel-platinum group elements and massive sulphide (copper-zinc-gold-silver) resource potential.

Mapping in the Tehery Region

- Multiple kimberlite (diamond) indicator minerals were found in glacial sediments south of Meen Lake, north-west of Hudson Bay, indicating a clear diamond potential.
- Working with the University of New Brunswick, researchers developed a more accurate classification method for remote mapping of surficial materials, helping to improve the geological assessment of the region at lower costs.

Finding Traces of Space

- While analyzing samples from sedimentary rocks of the Rae region in Nunavut, researchers with the Geological Survey of Canada made a rare discovery: presence 7-cm-thick bed of impact spherules, an indication of a large meteorite strike somewhere on Earth about 2.1 billion years ago.

South Rae

- One figure of the assembly of the Nuna Supercontinent and paleogeography at 2.3 billion years ago was featured in the Public Broadcasting Systems web-based television series NOVA Eons.
- The President of NexGen Energy requested that South Rae project team members present dedicated talks to their exploration staff in Vancouver because they recognized the importance of the new South Rae geological understanding to exploration on the Paterson Uranium trend.

Geo-Mapping for Energy and Minerals (GEM)

GSC STRATEGIC PRIORITY 1: GEOLOGICAL KNOWLEDGE OF CANADA'S ONSHORE AND OFFSHORE LANDS

Region	Objective	Highlights & Successes
Cordillera	The Cordilleran region has a substantial mineral endowment. It hosts a multitude of mineral deposits (gold, copper, lead, and zinc). New geoscience knowledge in this area will drive the discovery of new mineral deposits and help increase known resources.	**A New Klondike Gold Rush** • Collaborative research between GEM and the United States Geological Survey (USGS) found a historically important gold bearing geological unit (Klondike-like) in western Yukon extends into eastern Alaska. Recognizing the new extents of this unit will be of interest to companies exploring for sources of placer gold at the international level. **Stikinia Bedrock** • GEM research indicates that previous interpretations of faults and terrane boundary relationships require significant reassessment. Proper recognition and understanding of these relationships can help identify new areas with resource potential for minerals that are known to occur in the region, such as copper and gold. **Additional Gold Potential in British Columbia** • Two companies, Grey Rock Resources and Brixton Metals Corporation, cite a joint BCGS-GEM report that recognizes a new potential bedrock source for placer gold in Atlin, British Columbia. Subsequently, visible gold found by Grey Rock initiated a staking rush over 120,000 hectares of land in the area. Brixton Metals now reports there is additional exploration potential in their 979 km^2 wholly owned Atlin Gold Project, where this bedrock source is situated. **Pioneering New Fault Direct-Dating Technique** • In collaboration with Portsmouth University, UK, GEM is conducting one of the first studies to use a new technique dating calcites found on fault surfaces. A better understanding of this geological information can help locate new areas with resource potential for minerals, known to occur in the region such as copper and gold.
Baffin	This region covers the offshore and onshore areas around Baffin Island. The goal is to complete comprehensive geological framework mapping of these of the North that have the highest resource potential.	**Onshore Mapping** • Four new stratigraphic sections depicting how rock layers are deposited, including succession and age, were measured on Bylot Island., Northern Baffin Island. Common stratigraphic succession allow identification of regional and local unconformities, and help sequence a stratigraphic framework for the offshore succession. **Baffin Bay Petroleum Systems** • A GEM study provided a good understanding of the geological history and plate tectonic evolution of the sedimentary basins and the factors that control the petroleum resource potential in the area. **Filling Knowledge Gaps** • Southern Baffin Island represent some of the last major missing tectonic pieces in our understanding of Nunavut geology. Targeted bedrock mapping was conducted to resolve this uncertainty. **Noble Energy Takes An Interest** • Don Yezerski of Noble Energy contacted a GEM scientist following a poster presentation at the American Association of Petroleum Geologists (AAPG) Annual Conference and Exhibition (ACE) in May 2019. Mr. Yezerski was interested in the new age constraints and thermal data for the Paleozoic of the Labrador margin that she presented at the conference.

Geo-Mapping for Energy and Minerals (GEM)

GSC STRATEGIC PRIORITY 1: GEOLOGICAL KNOWLEDGE OF CANADA'S ONSHORE AND OFFSHORE LANDS

Region	Objective	Highlights & Successes
Western Arctic	Covering the Western Canadian Arctic Archipelago, research in this region uses data acquired by GEM, the United Nations Convention on the Law of the Sea (UNCLOS) and industry seismic surveys. Integration of recent Arctic mapping projects will improve the understanding of bedrock geology and geological history.	**Smoking Hills** • GEM work is helping clarify the bedrock units within the Smoking Hills, information that is necessary for correlation to other GEM Arctic Margins study areas, including the offshore Canada Basin. Fieldwork determined that earlier mapping was incorrect. Observations now help resolving questions about kimberlite (diamond) indicator mineral studies on Banks and Victoria Islands, and are critical to supporting the continued success of regional mineral exploration. • Fieldwork along Horton River was able to identify 'smoking' bocannes at numerous sites, providing a characterization of them, and discovered naturally occurring hyper-acidic waters down to a pH of -1.44, stronger than sulphuric acid. **Richardson Mountains** • Scientists recognized a different rock formation, in the Richardson Mountains, providing an unknown link between Arctic Alaska to Canada's Sverdrup Basin. • Identification of an outcrop in the White Mountains uplift, shows a clearly different geological formation than the rest of the Richardson Mountains. Researchers can now determined fault mechanisms to explain how it was uplifted.
Hudson Ungava	The Hudson Bay region represents a large, poorly known part of Canada from both energy and mineral potential perspectives. New mapping and geochemical studies will better resolve petroleum potentials within the basin.	**Saglek Block** • An airborne high-resolution geophysical survey was completed and together with aeromagnetic maps provide nearly seamless coverage from the Labrador Trough to the Labrador coast. Early results indicate a substantial expansion of potential gold-hosting rocks, as well as prospective areas for rare-earth deposits. • Continued exploration in the Hopedale Block by Labrador Gold is yielding positive results. GEM's aeromagnetic high-resolution map provides valuable new information. **Southampton Island** • A magnetotelluric survey was completed to map the extent of hydrothermal dolomites, an important factor contributing to the petroleum prospectively within the Hudson Basin. **Core Zone – Integrated Geoscience** • Discovery of a new, 2170 Ma Large Igneous Province in the Labrador Trough adds new perspective on the evolution and mineral potential of the area. • Midland Exploration is focusing on new targets identified by the GEM program in the Core Zone for their nickel, copper cobalt (Ni-Cu-Co) Soissons projects. • New tectonostratigraphic models also provided new information for Midland Exploration for precious metals (Willbob gold project), as well as for Northern Shield Exploration for base metals. **Hydrocarbon Source Rocks** • Recent laboratory analyses indicate that organic matter-rich source rocks from outcrops can be more matured than previously suggested by conventional analytical methods. This finding increases the petroleum prospectivity of the basin.

Geo-Mapping for Energy and Minerals (GEM)

GSC STRATEGIC PRIORITY 1: GEOLOGICAL KNOWLEDGE OF CANADA'S ONSHORE AND OFFSHORE LANDS

Region | **Objective** | **Highlights & Successes**

Region: Collaboration with Communities

Objective:

One component of the GEM program is to provide geological knowledge to residents of the North and their institutions, as well as provincial/territorial jurisdictions with land-use and resource management responsibilities.

GEM is expanding its community engagement activities in recognition of the need to engage Northerners and their institutions at all stages of GEM activities.

Highlights & Successes:

Advisory Group of Northerners

- GEM established an Advisory Group of Northerners, representing the diversity of the Northern context, such as Indigenous socio-economic development organizations, the private sector and territorial governments to provide advice on approaches that can be implemented to successfully deliver geoscience knowledge to Northerners.
- GEM has conducted 8 annual meetings to date across the North to solicit feedback and ideas to benefit the delivery of geoscience knowledge to northern communities.

Engagement with Communities

- Since 2013, GEM scientists and engagement officers have visited more than 65 Northern and Indigenous communities and holding over 450 meetings/events with representative organizations, hunters and trappers committees, community corporations, public meetings, and other public events.

Community Research-Sharing and Close-outs

- With the completion of GEM research, scientists and engagement officers have been touring communities to present research results, so landholders have relevant information about inform decision making about land-use.
- Through dialogue and information sharing, GEM research sharing sessions have been helping building positive relationships with communities. An on-going responsibility of the program and critical for continued successful geoscientific initiatives in the North.

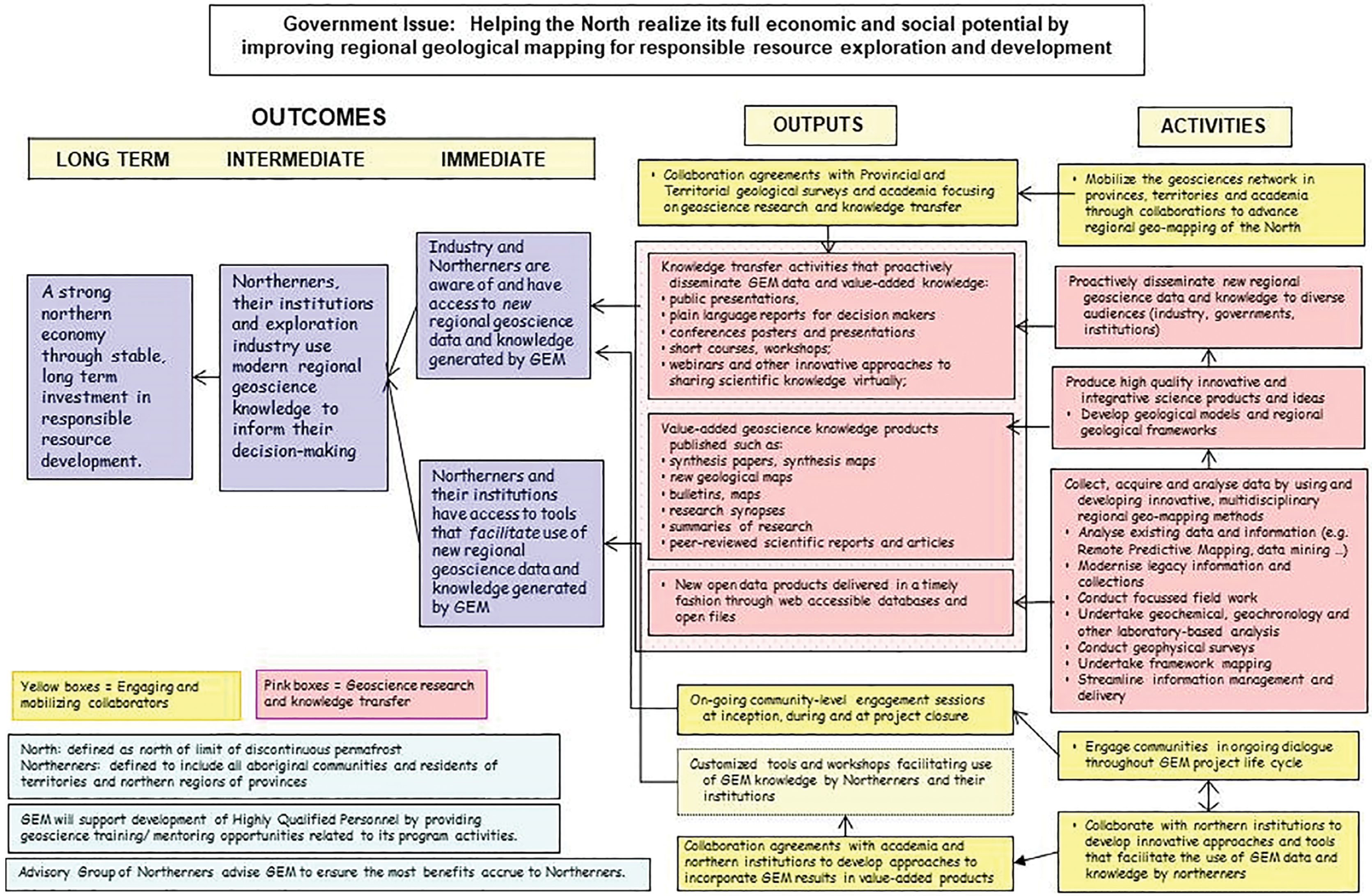
Geoscience Field School

- GEM held a geoscience field school in the community of Toloyoak, Nunavut in 2016. More than 160 community members of all ages took part in the geological field school, occurring over five days.
- The field school presented a unique opportunity for residents to learn more about the geological features of their land, and it expanded on local and traditional knowledge.
- The geoscience lessons were broken down into teachable blocks, covering topics such as rocks and minerals, ancient ice sheets, geophysics, geocaching with GPS, and mapping with GIS software.

Grants & Contributions

- Collaborating and funding regional organizations through grants and contributions to integrate geological knowledge to traditional knowledge in the creation of tools, like maps, that help clarify mining and energy development probability to allow inform land and resource development decisions.
- Since 2013, up to $4,640,000 were provided.

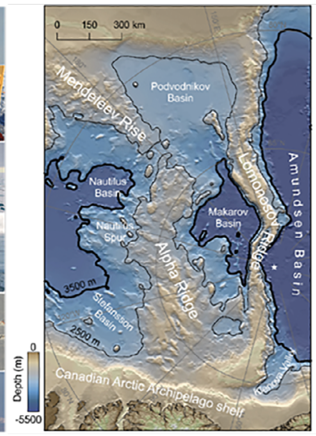
Geo-Mapping for Energy & Minerals (GEM)

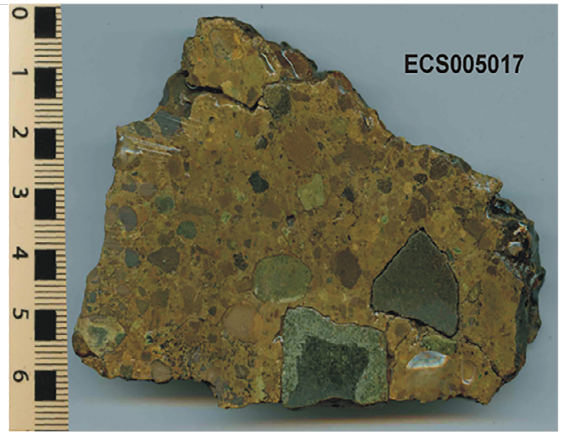


GSC STRATEGIC PRIORITY 1: GEOLOGICAL KNOWLEDGE OF CANADA'S ONSHORE AND OFFSHORE LANDS

United Nations Convention on the Law of the Sea (UNCLOS) Program

Why? The Government of Canada has as an obligation as a signatory to the United Nations Convention on the Law of the Sea (UNCLOS) to define its continental shelf using scientific data





Project Success Stories

Canada's Arctic Ocean submission

- The outer limits of Canada's continental shelf are defined by 877 coordinates. The outer limits enclose an area of 1.2 million square kilometers beyond the Canada's 200 nautical mile exclusive economic zone (EEZ), that includes the geographic North Pole.
- Canada's submission was filed at the United Nations on May 23, 2019. The submission is 2100 pages in length contained in 20 documents that lay out the scientific data and rationale for Canada's entitlement to the continental shelf. The Executive Summary is publicly available in both official languages.

Data collection

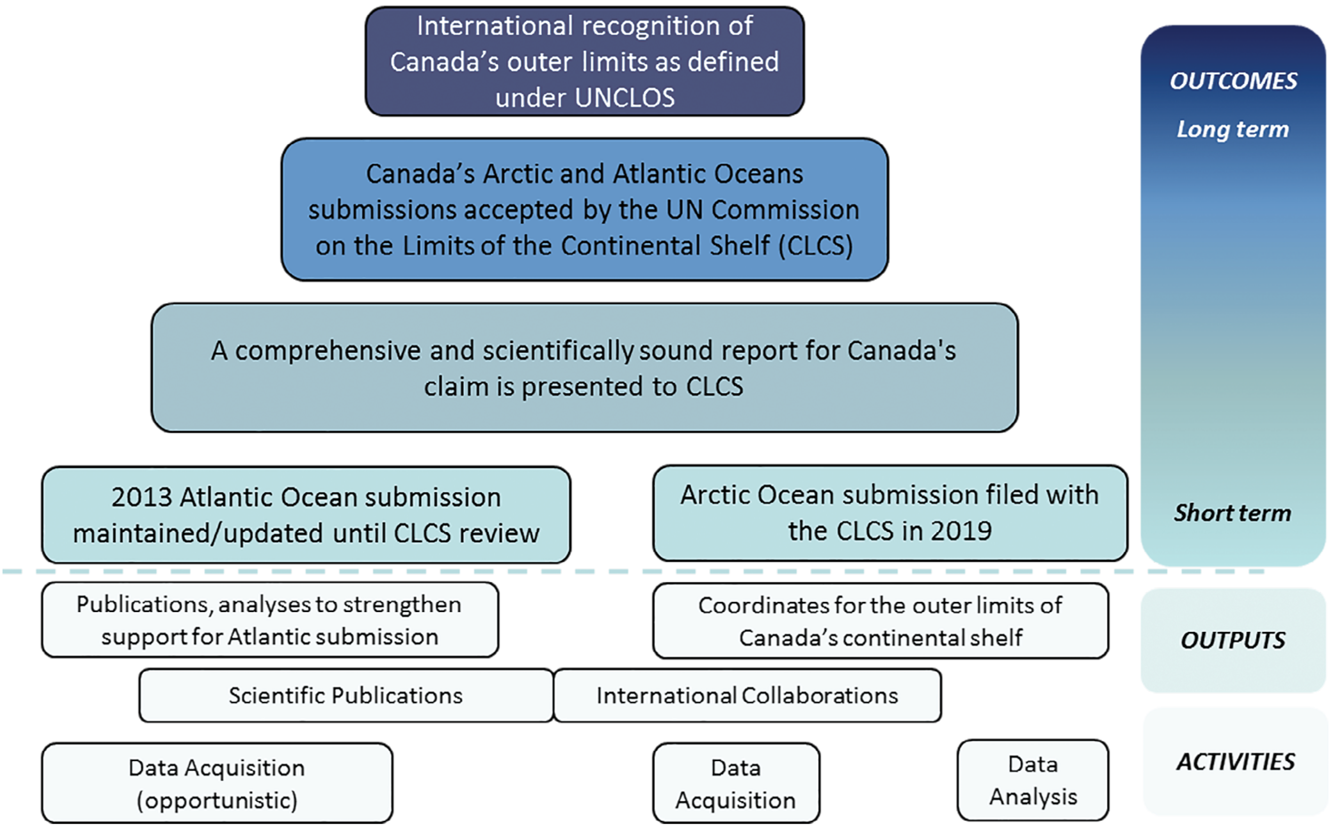
Bathymetric and geoscientific data were acquired over a decade working under harsh conditions:

- 18,709 km of multi-channel seismic reflection data.
- 773 recordings of seismic wide-angle reflection and refraction data.
- 90,000 km single-beam and multi-beam bathymetric, sub-bottom profiler and gravimeter data.
- 800,000 km^2 of aero-gravity and aero-magnetic data.
- More than 800 kg of rocks dredged from five sites and piston cores acquired at three sites.

Scientific results

- The Central Arctic Plateau (Lomonosov Ridge, Alpha Ridge, Mendeleev Rise) is an interconnected submarine elevation with continental affinities that is composed of thickened crust (20-30 km thick). It has geomorphological and geological continuity with the Canadian continental margin and landmass.
- The development of Alpha Ridge has been shaped in large part by plume-related events in the High Arctic Large Igneous Province (HALIP) that can be traced back to the Canadian Arctic islands.
- On the North American side, the Central Arctic Plateau is morphologically continuous with the landmass of Canada across the narrow geological shelf north of Ellesmere Island.
- Canada regards all elements of its continental margin as being in geological continuity. As a result, the application of both the distance and depth constraints of UNCLOS Article 76 have been invoked to delineate the outer limits of Canada's continental shelf.

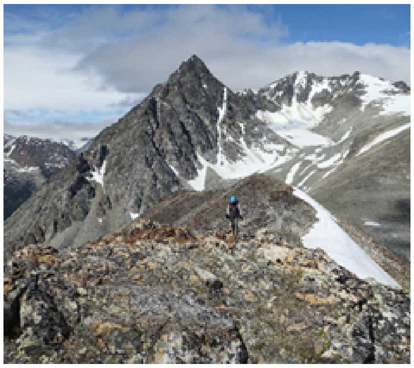
UNITED NATIONS CONVENTION ON THE LAW OF THE SEA (UNCLOS) PROGRAM (2019-2024)

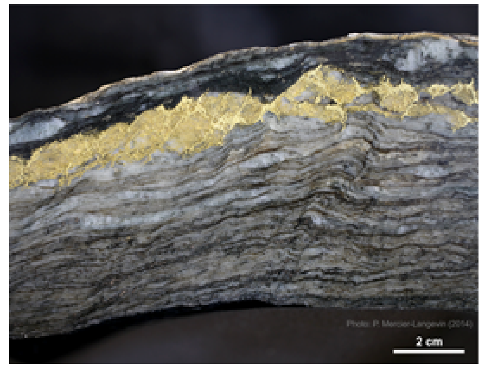


GSC STRATEGIC PRIORITY 2: GEOSCIENCE FOR SUSTAINABLE DEVELOPMENT

Targeted Geoscience Initiative

Why? To provide the mineral exploration industry with new ore system models and innovative methodologies to enhance effectiveness of deep exploration for Canada's key economic minerals and to reduce some of the risks of mineral exploration and support Canadian mining-dependent communities.





Objective	Goals	Success Stories
Modelling Ore Systems at depth	Better understand the processes underlying and the development of five ore systems in Canada to inform mineral exploration and increase the economic sustainability of current mines. This ore systems are: • Gold • Nickel-Copper-Platinum Group Element (PGE) deposits • Porphyry • Uranium • Volcanic- and sedimentary-hosted base metal	• Identification of new distribution pattern of gold (controlled by discrete faults cross-cutting the folds, rather than the fold pattern itself) is redefining search criteria in the Banded Iron Formation (BIF) host rocks. • New field observations and age calculations carried out on volcanic sedimentary hosted hyper-enriched black shale deposits located in Yukon have re-defined the accepted exploration model these deposits in Canada and abroad.
Developing the new generation of highly qualified personnel	Participate in the training and mentoring of students to increase the number of Highly Qualified Personnel (HQP) available to the mineral industry	• 45 students and 9 post-doctoral fellows were trained to lead the future search for mineral deposits in Canada and worldwide. • Structural mapping and geochronology work by MSc and PhD students redefined the distribution pattern of gold from the Banded Iron Formation host rocks which improves the search criteria used to find new deposits.
Developing transferable models	Integrate multi-scale scientific knowledge of sources of metals and the pathways they take to become an ore deposit in a way that is transferable across locations and that can be used by industry to innovate their exploration approaches	• Co-development between multi-sectorial partners of a new style of uranium ore genesis that is distinct from the standard model present elsewhere in the Athabasca. • Co-created public geoscience knowledge has resulted in the expansion of Canada's newest gold-mining district of the Meliadine, Meadowbank, and Amaruq deposits in the Kivalliq District of Nunavut.

Targeted Geoscience Initiative (Phase 5) Logic Model

Source-to-ore geoscience for effective exploration

Issue NRCan SO 1 – Canada's natural resource sectors are globally competitive
PA 1.3 – Investment in natural resource sectors

Ultimate Outcomes	**Economic prosperity and job opportunities improve** in mineral producing regions of Canada through increased discovery and development of mineral resources	**Global competiveness** of Canada's exploration industry is enhanced through decreased costs and risks of mineral discovery.	
Long-term outcomes *(2020 and beyond)*	New knowledge, methodologies and models enhance the exploration industry's ability to detect buried ore deposits.	Integrated, multi-scale scientific knowledge of source-to-ore formation that is both authoritative and accessible results in industry innovating exploration approaches.	A replenished pool of highly qualified personnel equipped with state-of-the-art knowledge, is available for employment in the mineral exploration industry.
Intermediate Outcomes *(by 2019)*	Innovative methodological approaches for detection and delineation of ore deposits begin to be adopted by industry.	Exploration industry starts to apply new public geoscience knowledge to explore for Canada's major mineral deposit types.	
Immediate Outcomes *(by 2017)*	Mineral exploration industry can efficiently discover recent and emerging public geoscience knowledge and methodologies relevant to discovery of new mineral resources	Collaborative geoscience research groups, that engage students, are formed to leverage expertise and capacity to effectively solve research questions about genesis of ore systems.	

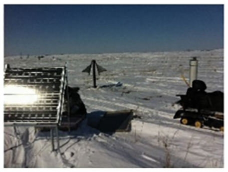
Source-to-ore geoscience for effective exploration

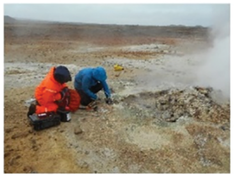
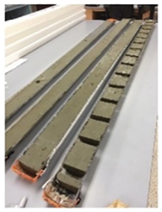
Ultimate Outcomes	**Economic prosperity and job opportunities improve** in mineral producing regions of Canada through increased discovery and development of mineral resources	**Global competiveness** of Canada's exploration industry is enhanced through decreased costs and risks of mineral discovery.	
Outputs	Results of proof-of-concept testing of methodology *- Publicly available results from field tests of innovative methodologies that target markers of ore forming processes.* *-Innovative geochemical, geophysical and mineralogical indicators that target buried ore environments*	Open Public Geoscience Knowledge Products *- Expedited scientific publications that make available data sets and preliminary interpretations relevant to mineral exploration.* *- New authoritative syntheses of leading-edge knowledge of Canada's economically important mineral systems.* *- Presentations at workshops, field and short courses, seminars and online publications, targeted to stakeholder needs.*	Student theses, projects, reports and databases that address geoscience questions related to ore deposits.
Activities	Develop methodologies targeted to measureable markers of ore system processes (New and Improved Methodologies) *- Improve and develop methodologies that target detection of buried mineral deposits* *- Carry out proof-of-concept testing.*	Carry out public geoscience research on ore system processes (New Geoscience Knowledge) *- Collaborate on geoscientific studies with industry, academia (including students) and Provincial-Territorial Geological Surveys.* *- Compile existing and collect new data, scientifically analyze, interpret and synthesize data into new ore system knowledge* *- Develop new geological models and identify measureable markers of ore deposit formation*	
	Disseminate public geoscience (Open Geoscience) *- Develop expedited, publicly-accessible, national framework for discovery of data and knowledge pertinent to mineral exploration* *- Produce and provide to industry the latest scientific knowledge of ore systems and their genesis* *- Develop and test new methodological approaches for detection and delineation of buried ore deposits.* *- Train new student HQP in innovative approaches to ore systems geoscience*		

GSC STRATEGIC PRIORITY 2: GEOSCIENCE FOR SUSTAINABLE DEVELOPMENT

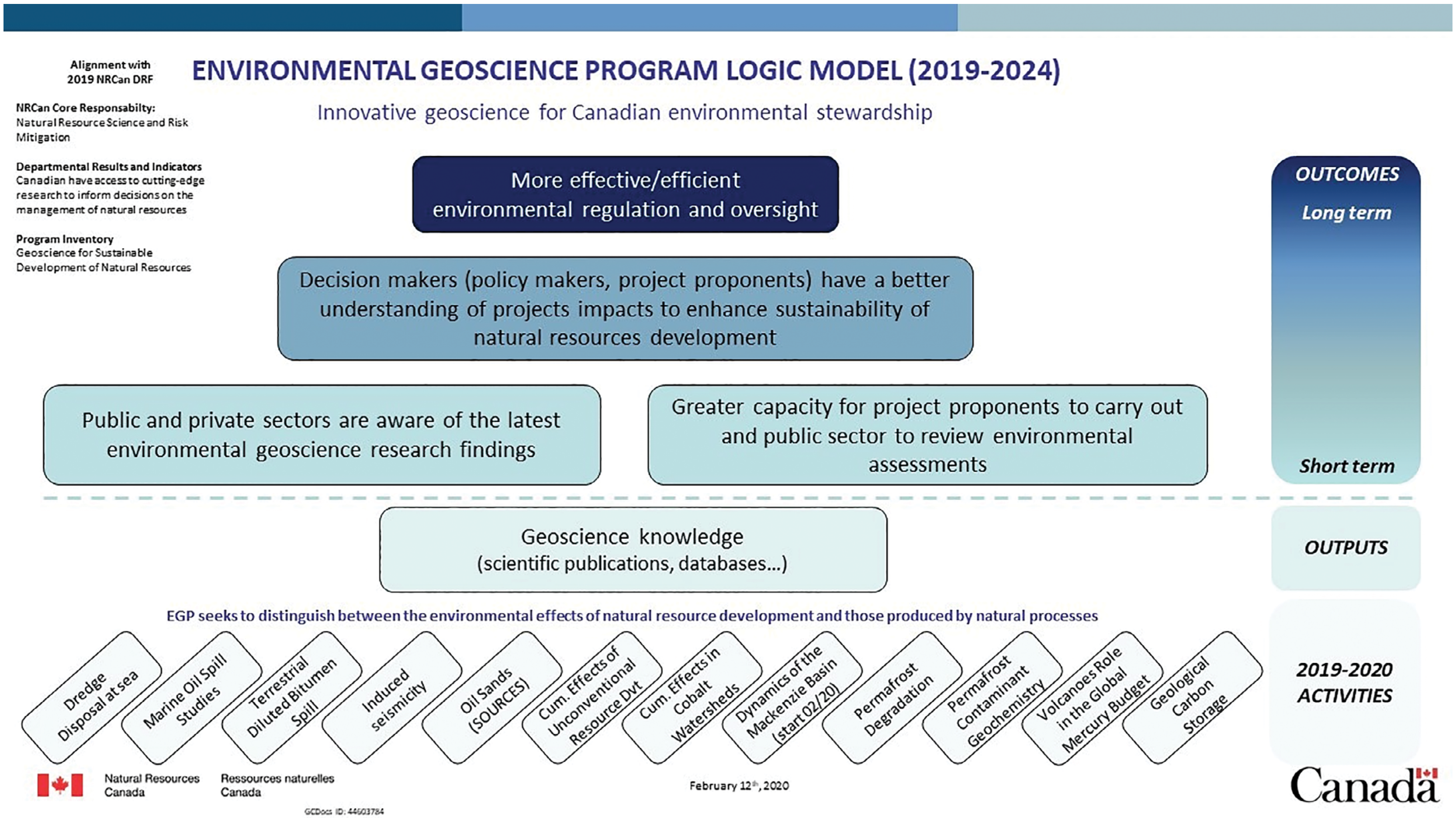
Environmental Geoscience Program

Why? To distinguish the environmental effects of natural resource development from those occurring naturally and to develop new methodologies in geoscience supporting the sustainable development of Canada's natural resources.

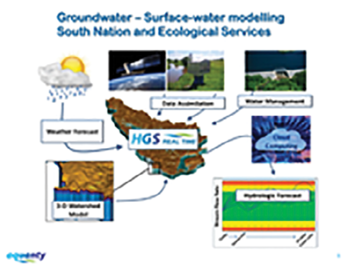
Project	Project Goal
Induced Seismicity	• Provide accurate determination of the locations and depths of shallow induced earthquakes and densify seismograph coverage of the Montney in northeast BC to capture induced earthquakes associated with local hydraulic fracturing operations.
Oil Sands (SOURCES)	• This research will define in detail the processes that are attenuating the Oil Sand Processed Water (OSPW) plume at the research site.
Geological Carbon Storage	• Studies within the project are focused on the development of improved monitoring methodologies and a better understanding of the relationship between $C0_2$ injection and induced seismicity.
Dredge Disposal at Sea	• NRCan contributions to National Guidelines for disposal at seas site licensing. During field work, will deploy and recover scientific moorings.
Cumulative Effects in Cobalt Watersheds	• Investigate ways of unraveling the spatio-temporal history of cumulative environmental effects in watersheds of the Cobalt region impacted by almost a century of mining activity.
Environmental impacts of Permafrost Thaw in the Arctic	• **Permafrost Degradation** Provide baseline characterization to develop and adapt methods to assess and monitor permafrost impacts. • **Permafrost Contaminant Geochemistry** Develop conceptual basis for understanding how solutes move through a permafrost landscape, the major knowledge gap (Arctic contaminants).
Cumulative Effects of Unconventional Resource Development	• Study potential impacts of hydrocarbon development in an active production area.
Geoscientific Research into Accidentally Spilled Petroleum (GRASP)	• **Environmental Impacts of Diluted Bitumen (Dilbit)** Better understand the behaviour and fate of diluted bitumen (dilbit) accidentally released to the environment. • **Marine Oil Spill Studies (MOSS)** Establish a baseline of current and past variability in physico-chemical properties and microbial/microplanktonic populations.
Volcanoes role in the Global Mercury Budget	• Measure Hg emissions from vents and fumeroles around Icelandic volcanoes and separate geothermal systems which collectively may be among the largest emitters of magmatic gases in the Northern Hemisphere.

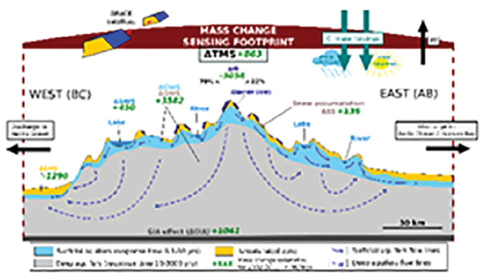

Alignment with
2019 NRCan DRF
ENVIRONMENTAL GEOSCIENCE PROGRAM LOGIC MODEL (2019-2024)
Innovative geoscience for Canadian environmental stewardship
NRCan Core Responsabilty:
Natural Resource Science and Risk Mitigation
Departmental Results and Indicators
Canadian have access to cutting-edge research to inform decisions on the management of natural resources
Program Inventory
Geoscience for Sustainable Development of Natural Resources
More effective/efficient environmental regulation and oversight
Decision makers (policy makers, project proponents) have a better understanding of projects impacts to enhance sustainability of natural resources development
Public and private sectors are aware of the latest environmental geoscience research findings
Greater capacity for project proponents to carry out and public sector to review environmental assessments
OUTCOMES
Long term
Short term
Geoscience knowledge
(scientific publications, databases...)
OUTPUTS
EGP seeks to distinguish between the environmental effects of natural resource development and those produced by natural processes
Dredge Disposal at sea
Marine Oil Spill Studies
Terrestrial Diluted Bitumen Spill
Induced seismicity
Oil Sands (SOURCES)
Cum. Effects of Unconventional Resource Dvt
Cum. Effects in Cobalt Watersheds
Dynamics of the Mackenzie Basin (start 02/20)
Permafrost Degradation
Permafrost Contaminant Geochemistry
Volcanoes Role in the Global Mercury Budget
Geological Carbon Storage
2019-2020
ACTIVITIES
Natural Resources Canada
Ressources naturelles Canada
February 12th, 2020
GCDocs ID: 44603784
Canada

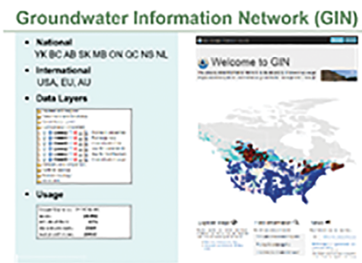
GSC STRATEGIC PRIORITY 2: GEOSCIENCE FOR SUSTAINABLE DEVELOPMENT

Groundwater Geoscience Program (GGP)

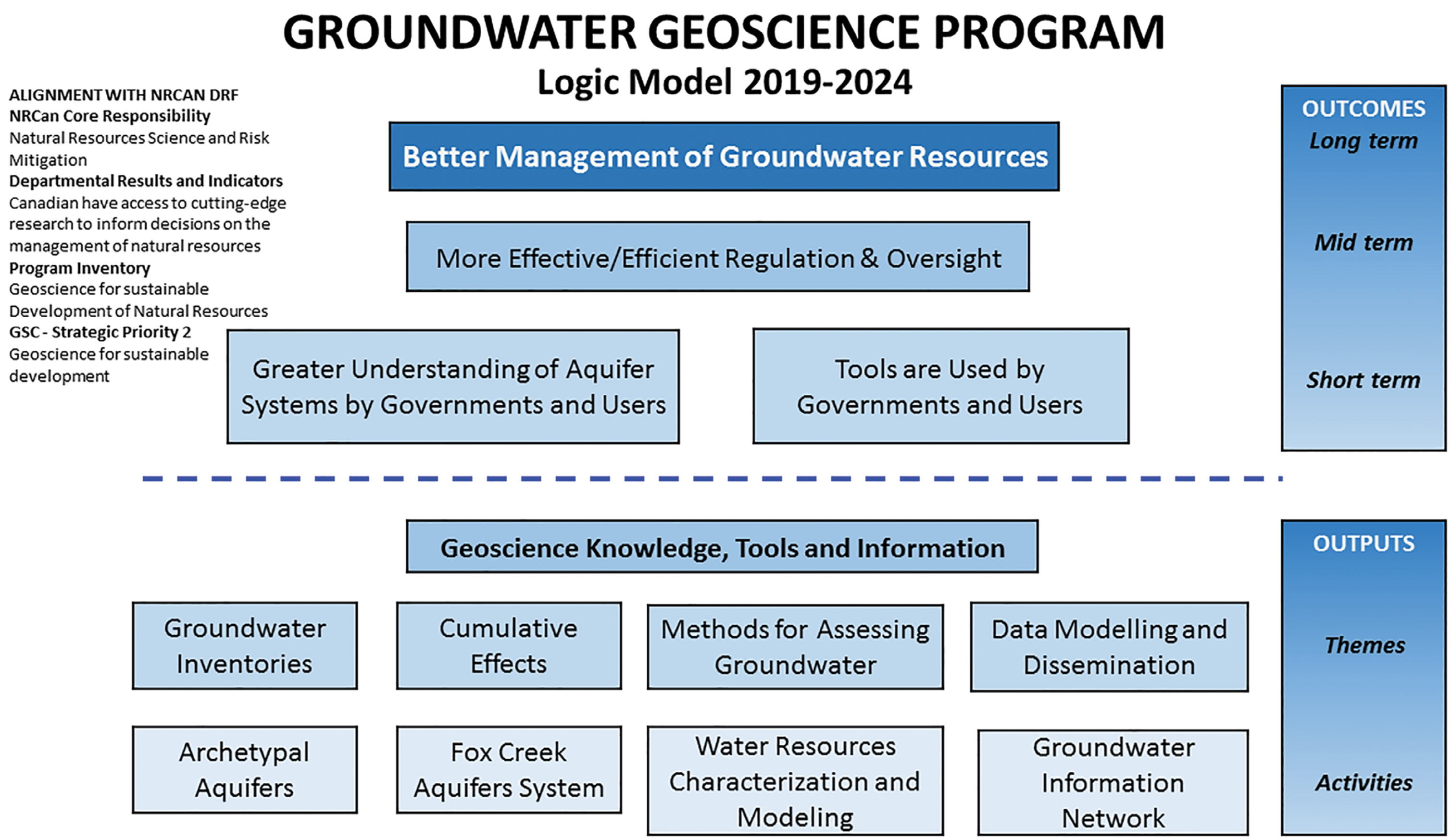
WHY? To better understand groundwater distribution, quantity, flow dynamics and possible impacts on Canada's sustainable development.







Project	Project Goal
Archetypal Aquifers in Canada	• Aquifers classification: develop aquifer system nomenclature in glacial terrains. • Case studies: consolidate literature and complete data collection to support archetypal aquifers descriptions. • Methods development: downhole and near surface geophysics, seismic signal processing, machine learning. • Modelling: physical based numeric groundwater modelling at watershed to regional scales. • Collaboration: integrate with academia, federal departments (AAFC) and provincial ministries
Groundwater Information Network (GIN)	• National groundwater web portal and database for groundwater data (GIN). • National Permafrost Information Network (PIN), including web portal and database. • Dynamic summary "dashboard" development for any aquifer in GIN with BC collaboration. • Maintain and advance relevant geoscience data standards. • Prototype linked data infrastructure for Canada-US water data.
Water Resources Characterization and Modelling	• Platform development supporting surface and groundwater allocations assessing water resources and forecast their future under climate changes and anthropogenic stresses. • Development of hydrogeological characterization approaches including learning machines to translate geophysical data in hydraulic properties and high-resolution hydraulic testing for complex aquifers. • Quantify changes in glacial meltwater inputs into the hydrological system, and assess the related impacts on the different water storage compartments (Canadian Rockies).
Assessment of aquifers in the Fox Creek area (AB)	• Study potential impacts of unconventional hydrocarbon development on aquifers in an active production area. • Characterize non-saline aquifers. • Conduct a groundwater geochemical baseline study. • Develop a coupled surface water / groundwater model. • Analyse the influence of induced seismic events on shallow aquifers.

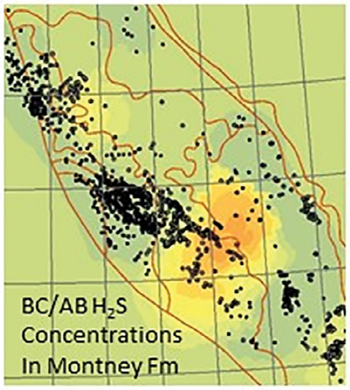


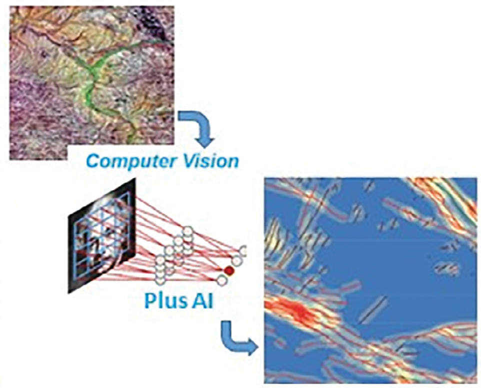
GROUNDWATER GEOSCIENCE PROGRAM
Logic Model 2019-2024
ALIGNMENT WITH NRCAN DRF
NRCan Core Responsibility
Natural Resources Science and Risk Mitigation
Departmental Results and Indicators
Canadian have access to cutting-edge research to inform decisions on the management of natural resources
Program Inventory
Geoscience for sustainable Development of Natural Resources
GSC - Strategic Priority 2
Geoscience for sustainable development
OUTCOMES
Long term
Better Management of Groundwater Resources
Mid term
More Effective/Efficient Regulation & Oversight
Short term
Greater Understanding of Aquifer Systems by Governments and Users
Tools are Used by Governments and Users
OUTPUTS
Geoscience Knowledge, Tools and Information
Themes
Groundwater Inventories
Cumulative Effects
Methods for Assessing Groundwater
Data Modelling and Dissemination
Activities
Archetypal Aquifers
Fox Creek Aquifers System
Water Resources Characterization and Modeling
Groundwater Information Network

GSC STRATEGIC PRIORITY 2: GEOSCIENCE FOR SUSTAINABLE DEVELOPMENT

Geoscience for New Energy Supply

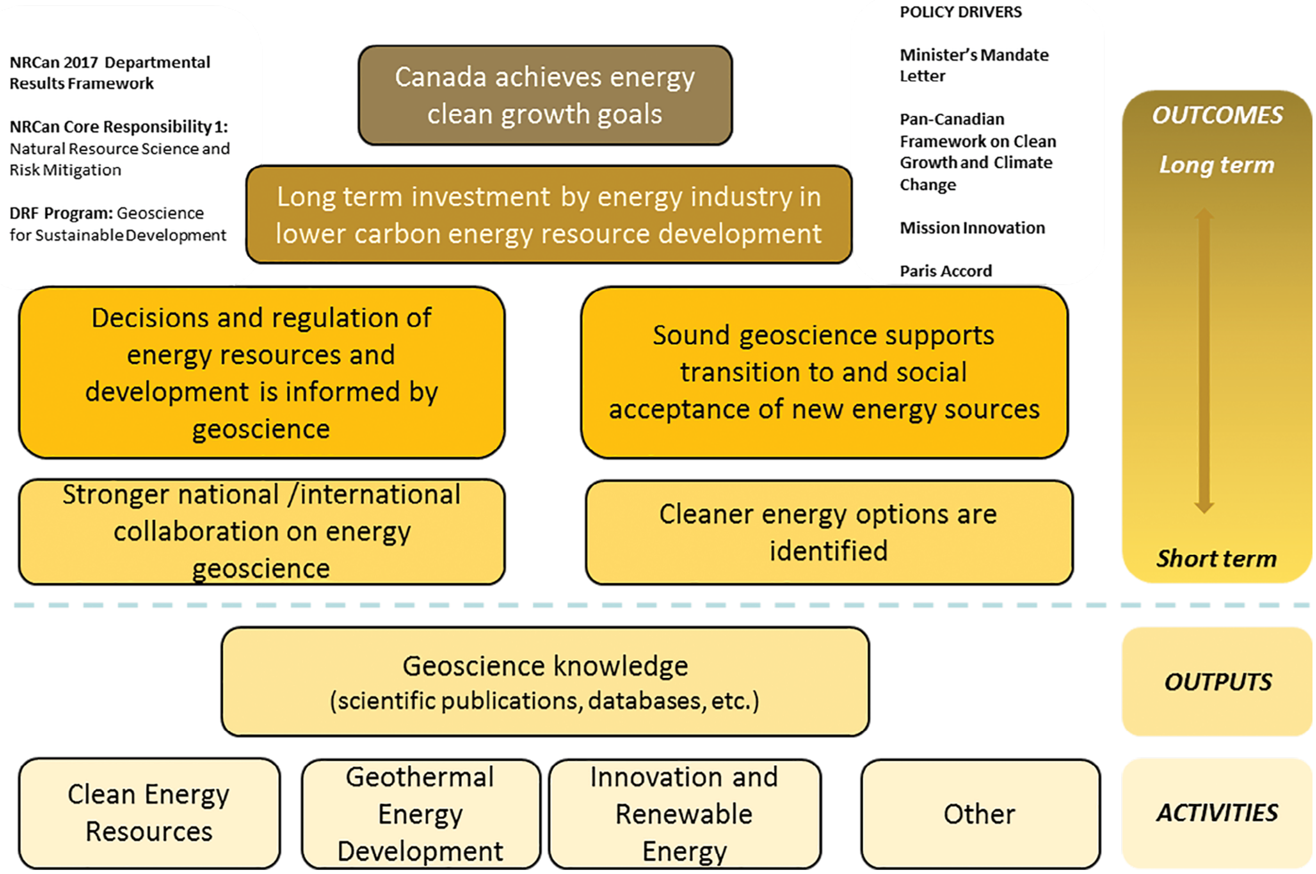
Why? To support strategies for our transition to a future low-carbon economy through clean energy research and development (R&D) and the promotion of non- and low-emitting energy resources. This will be done by using advancements in the fundamental understanding of Canada's sub-surface landmasses.





Project	Project Goal	Success Stories
Geothermal Energy	Supports government goals of reducing CO2 emissions by a transition to non-emitting energy resources by evaluating regional geothermal resources.	• Successfully ran field operations, including 33 people and 375 person days (33% female, 18% visible minorities). • Collected new MT, Gravity, Passive Seismic, DS, bedrock, and fracture data • Bottom well temperature data for St. Lawrence Lowlands Project have been provided by industry collaborators
Clean Energy Resources	Advancement of fundamental geoscience knowledge of Canada's sub-surface lands with the intent of improving our environmental performance during the development and production of tight oil and unconventional gas (TOUG). Such endeavours will ultimately support the global steps towards a low-carbon economy.	• Successfully completed fieldwork with the University of Liverpool in Ft Nelson area; • Stanford University researchers have also expressed keen interest in collaborating with the GSC on this activity. • GSC researchers invited to a KIGAM funded project workshop in Korea focusing on the Liard Basin research and exploring future collaborative potential between GSC and KIGAM • Preliminary results on H_2S sources have been submitted for publication and is currently under review • 8 industry collaborators are currently working with GSC researchers on the H_2S project; 2 more have express interest.
Innovation and Renewable Energy	Captures renewable and low-carbon energy geoscience research focusing on innovative and novel laboratory methods and the integration and application of Augmented Intelligence/Machine Learning in Canadian geoscience R&D.	• Developed collaboration with industry (Husky Energy) and 2 universities (UofC and CUP) • Developed collaborations with three USDOE laboratories • Explored collaborations with AGS and SGS on Nanoporosity research collaborations: Duvernay/Montney (AGS); Bakken (SGS). • Developed collaborative laboratory method development relationships with Petroleum University of China, The University of Utah, Western Cape University of South Africa, CanmetENERGY-Devon and CanmetMATERIALS-Calgary

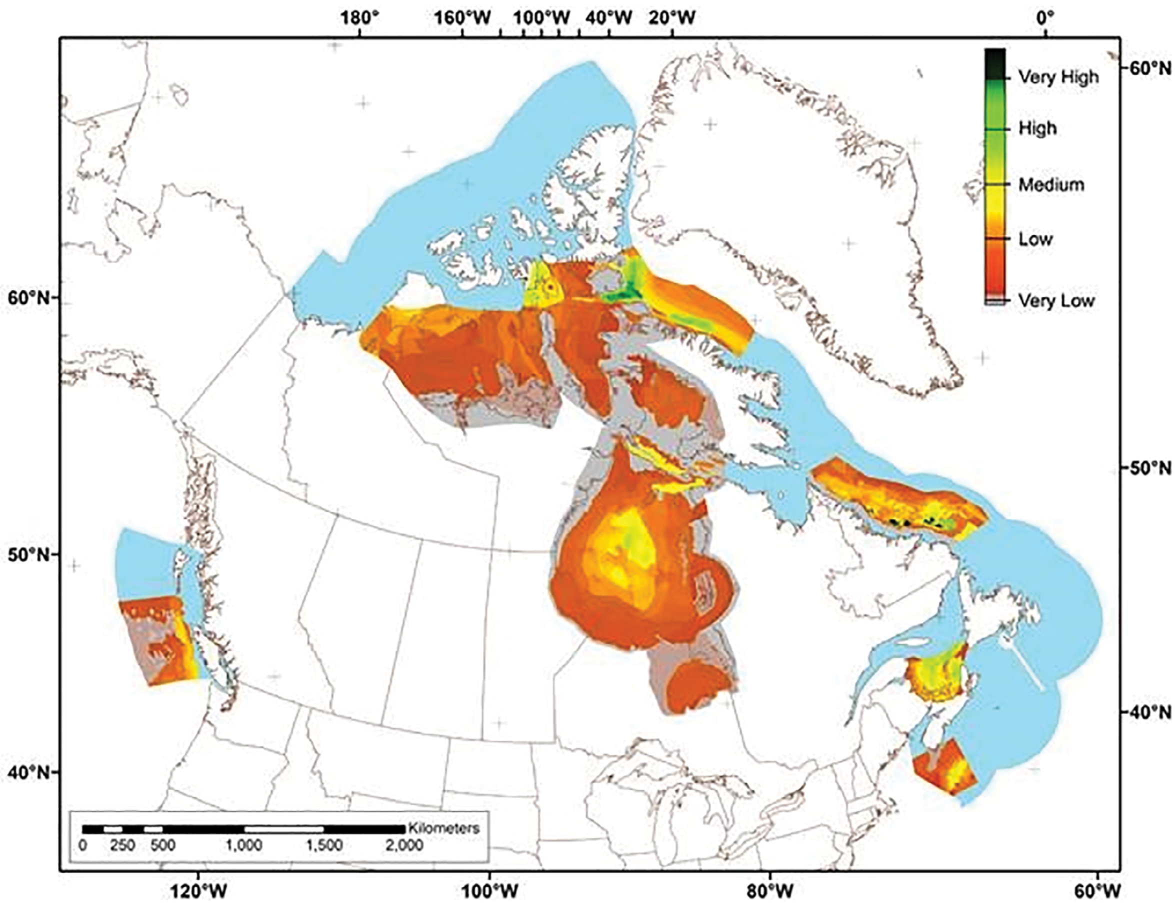
GEOSCIENCE FOR NEW ENERGY SUPPLY PROGRAM (2018-2023)



GSC STRATEGIC PRIORITY 2: GEOSCIENCE FOR SUSTAINABLE DEVELOPMENT

Marine Conservation Targets Program

Why? Provide estimates of offshore petroleum resource potential to inform decisions related to Canada's target of protecting 10% of its offshore by 2020.



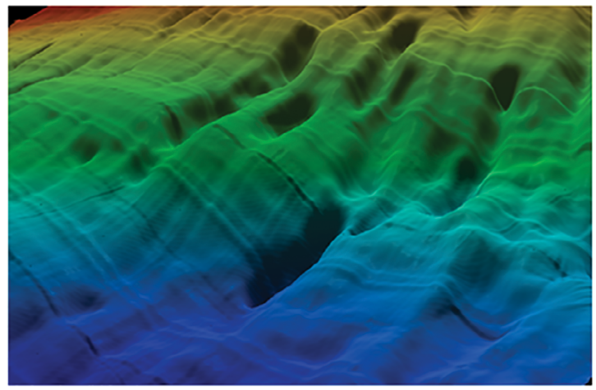
Map showing the likelihood of the presence of undiscovered oil and gas resources. MCT results as of March 2020

Project	Success Stories
Marine Conservation Targets	• Innovative mapping of areas of high, medium and low hydrocarbon potential to support Government of Canada's decision-making. • Development of tools, maps and reports for decision-makers with varying geoscience background, including new heat maps to portray a region's overall petroleum potential. • Assessments of the broader regions, thereby providing context and options, and increasing the value of the GSC work. • Release ofGSC Open Files of the MCT work so that GSC products for decision making are accessible and transparent.

GSC STRATEGIC PRIORITY 2: GEOSCIENCE FOR SUSTAINABLE DEVELOPMENT

Marine Geoscience for Marine Spatial Planning Program

Why? New maps and analyses of seafloor geology and active seabed processes will inform evidence-based marine spatial planning and regional environmental assessment.



Project goals

Marine Geoscience for Marine Spatial Planning

To contribute marine geoscience to integrated, regional assessment of environmental conditions so that projects can be planned and approved with a full understanding of site suitability and potential cumulative impacts, especially regarding:

(1) What is on the seabed?

e.g. *bedrock, sand, sediment, etc.*

(2) What are the geological processes affecting the seabed?

e.g. sediment transport, sediment erosion, sediment deposition

(3) Is the seabed unique, sensitive, or unstable?

Seabed mapping at three scales

Bioregional assessment	• Input to Department of Fisheries and Ocean Marine Atlases
Regional assessment	• Support regional environmental assessment for seabed-impacting marine activities
Targeted assessment	• Inform specific Department of Fisheries and Ocean-led spatial management measures

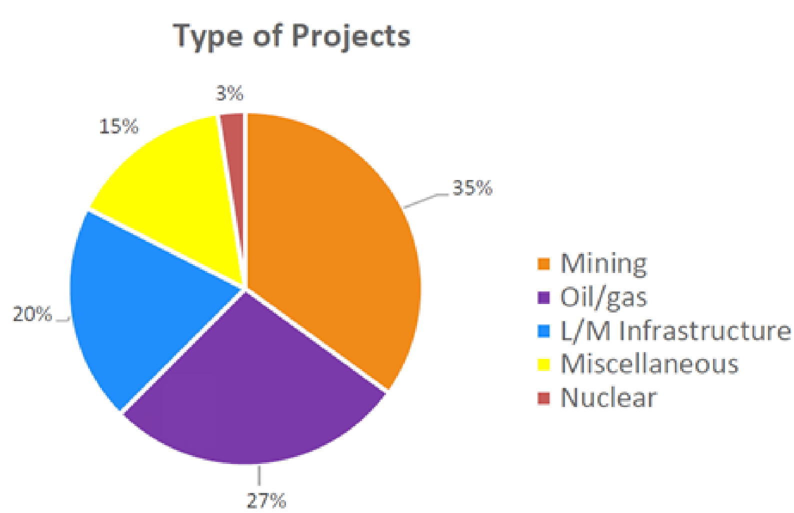
GSC STRATEGIC PRIORITY 2: GEOSCIENCE FOR SUSTAINABLE DEVELOPMENT

Impact Assessment Service

Why?

To support land-use planning and environmentally sound resource development, both on land and in our coastal and offshore waters. The GSC is the lead agency for evaluating geoscientific issues in environmental impact statements (EIS).

Project	Success Stories
EA reviews	Timely delivery of geoscience expertise for 40 EA projects, including: • Roberts Bank Terminal 2 (BC) – Hearings concluded in May 2019. GSC gave a presentation on seismicity and sea level issues in Vancouver May 2019. • Milton Hub (ON) - On a request by the Panel a groundwater presentation was made in June 2019. • GSC recommendations related to geohazards included for Nunavut Impact Review Board (NIRB) Strategic Environmental Assessments (SEA) July 2019 Vol. 1-3 Oil and Gas Development. • Frontier Oil Sands Mine Project proposed by Teck Resources Limited (AB) – Comments on groundwater issues has informed the commitments for the proponent.



GSC STRATEGIC PRIORITY 3: GEOSCIENCE FOR KEEPING CANADA SAFE

Public Safety Geoscience Program

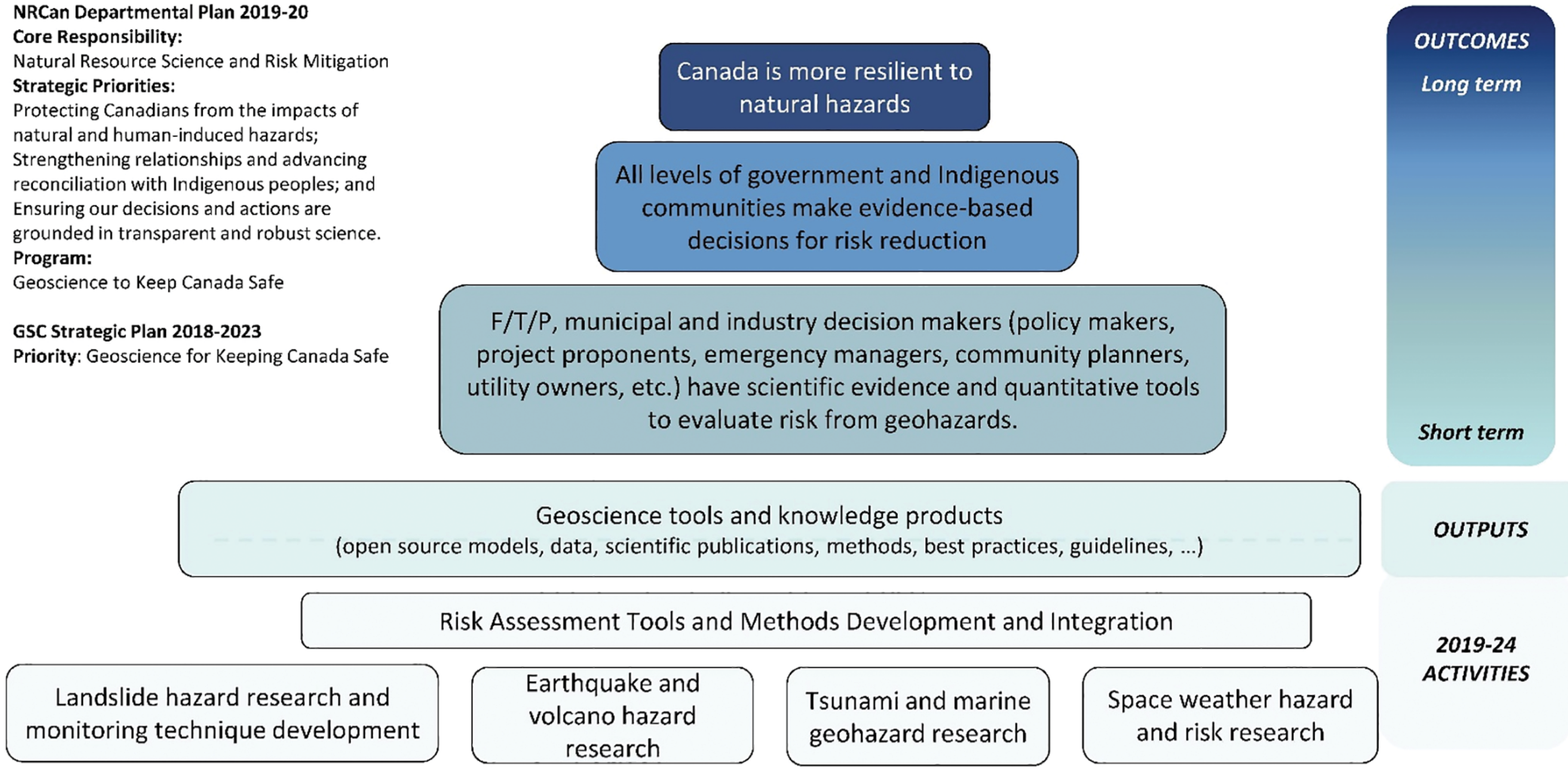
Why? To understand earthquakes, tsunamis, space weather, volcanoes, submarine and terrestrial landslides, and marine geohazards and their associated risks, and to work with stakeholders to inform safe development, land use planning, conservation efforts, and regulations.

Project	Project Goal	Success Stories
Earhtquake Geohazards	To understand hazards associated with earthquakes and volcanoes to inform national codes and standards, risk assessments, emergency management, mitigation planning and the development of early warning systems.	• Earthquake research contributes to the national seismic hazard model that informs seismic provisions in the National Building Code of Canada (and other national codes and standards). • Development of tsunami rupture models from earthquakes to support modelling of potential impacts and consequences. • The first volcanic ash fall susceptibility map for Canada was published as a GSC Open File.
Landslides and Marine Geohazards	To assess submarine landslide and turbidity current frequency, Arctic offshore conditions, and tsunami potential to protect population, infrastructure, and natural resources. To understand and monitor landslides in areas of key infrastructure.	• Surficial geology map series published with landslide inventory and terrain stability assessments for area of key oil and gas infrastructure development in BC. • Innovative landslide monitoring techniques at key test sites to support broader efforts in applying technology for decision making by train operators.
Space Weather Hazards	To improve monitoring and forecasting of geomagnetic storms and other space weather hazard events.	• NRCan chosen as a centre to supply space weather services to international aviation operations. • Establishment of a relationship between geomagnetic activity and Global Navigation Satellite System (GNSS) scintillation that is being used to develop forecasts of space weather effects on GNSS.
National-Scale Risk Assessment	To develop innovative multi-hazard risk assessment tools, guidelines and supports that enable Canada to strategically reduce risk from hazards and meet UNDRR Sendai Framework targets.	• Working with partners and collaborators to develop approaches to understand and mitigate against earthquake, tsunami, climate change and storm surge risks. • Development of an innovative web-based application for rapid risk assessment associated with seismic hazards (ER2). • Assessment of earthquake risk for Canada using OpenQuake software modelling in support of disaster risk reduction planning across Canada.

PUBLIC SAFETY GEOSCIENCE PROGRAM LOGIC MODEL (2019-2024)

NRCan Departmental Plan 2019-20
Core Responsibility:
Natural Resource Science and Risk Mitigation
Strategic Priorities:
Protecting Canadians from the impacts of natural and human-induced hazards; Strengthening relationships and advancing reconciliation with Indigenous peoples; and Ensuring our decisions and actions are grounded in transparent and robust science.
Program:
Geoscience to Keep Canada Safe

GSC Strategic Plan 2018-2023
Priority: Geoscience for Keeping Canada Safe



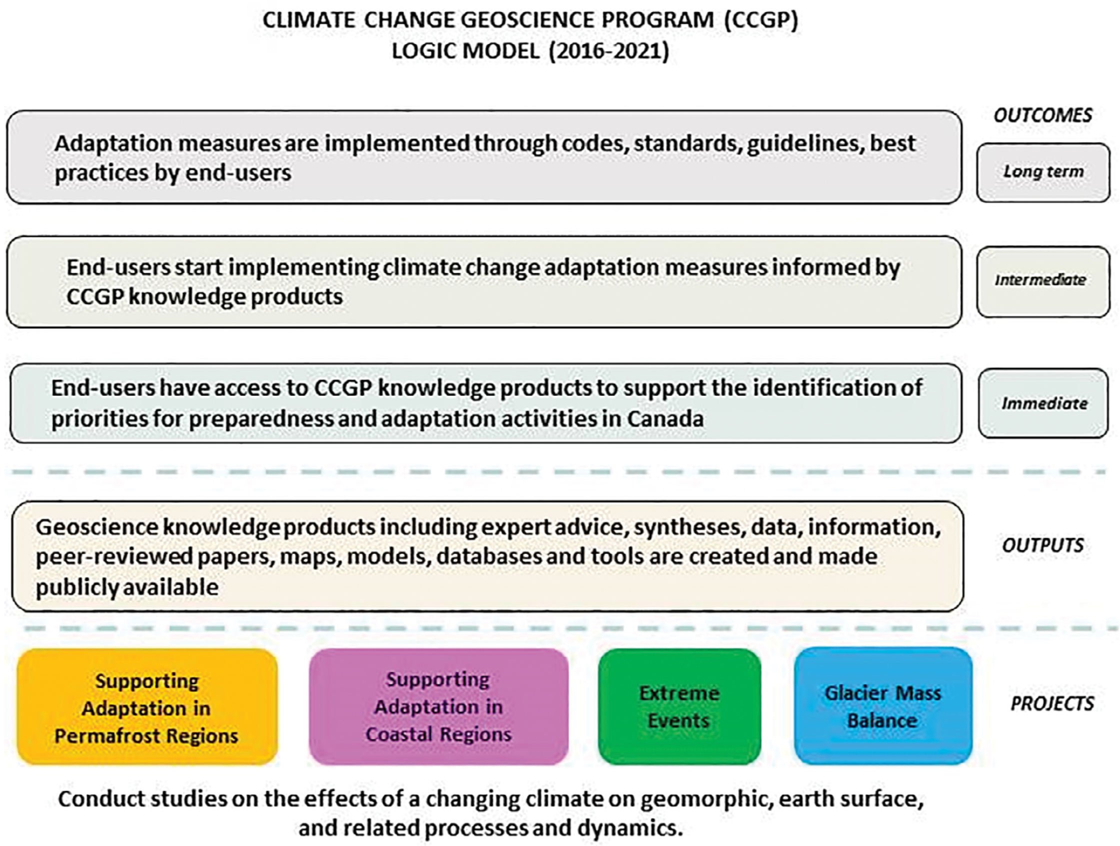
GSC STRATEGIC PRIORITY 3: GEOSCIENCE FOR KEEPING CANADA SAFE

Climate Change Geoscience Program

WHY? To better understand the geological impacts of climate change in Canada for land-use planning and government regulation to help at-risk communities to adapt.

Project	Goal	Success Stories
Supporting Adaptation in Permafrost Regions	To improve the understanding of permafrost-climate-infrastructure interactions, to inform the development of climate-change adaptation strategies for major existing and proposed transportation routes in Arctic and subarctic environments.	• Development of the Permafrost Information Network to ensure permafrost data are available to stakeholders for infrastructure and adaptation planning. • New approach developed to improve the national-scale permafrost map and provide better information on ground ice conditions for infrastructure planning and climate change adaptation. • Protocols for mapping permafrost landscape features along key northern transportation corridors to inform adaptation decisions.
Supporting Adaptation in Coastal Regions	To better understand the sensitivity of Canadian coastal regions to climate change, for the development of effective adaptation strategies for existing and proposed coastal infrastructure and communities.	• CanCoast, a national-scale database allowing innovative analysis of coastal sensitivity released 2019. • Coastal monitoring in Tuktoyatuk, NWT, and surrounding regions to aid local decision-making related to coastal change impacts • Development of national sea-level projections, based on an updated national model of crustal uplift.
Extreme Events	To improve flood forecasting of the Hudson Bay Lowlands to provide advance warning to First Nations communities and a long-term hydroclimatic record for improved hydroelectric water management.	• Document past river flow in eastern Labrador to benefit the Canadian hydro-power industry through a better understanding of the evolution of hydraulic regimes and to foresee potential climate change effects. • Development of a drone-based hyperspectral system for land cover validation providing improved knowledge of land surface change and implications for water storage.
Glacier Mass Balance	To quantify the rate and assess the causality of glacier-climate change in Canada's Arctic and Alpine environments.	• Development of a glacier mass balance model for the Canadian Rockies and Southern Interior Ranges to support decadal-scale water availability studies in western Canada. • Systematic glacier change observations reveal Canada's glaciers as the 3rd most important contributor to sea-level rise in the northern hemisphere.

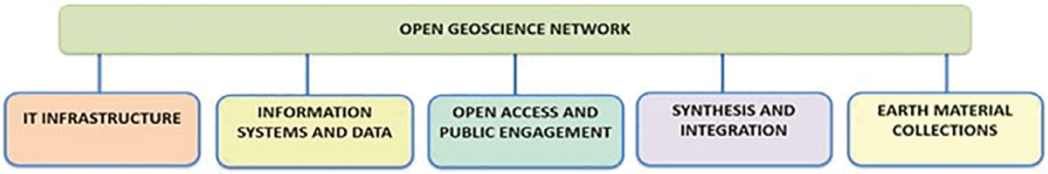
Significant Contributions to National Climate Change Assessment: ECCC *Canada's Changing Climate Report 2019:* a first-time overview of how and why Canada's climate, and IPCC *Special Report on the Ocean and Cryosphere in a Changing Climate.*


CLIMATE CHANGE GEOSCIENCE PROGRAM (CCGP)
LOGIC MODEL (2016-2021)
OUTCOMES
Adaptation measures are implemented through codes, standards, guidelines, best practices by end-users
Long term
End-users start implementing climate change adaptation measures informed by CCGP knowledge products
Intermediate
End-users have access to CCGP knowledge products to support the identification of priorities for preparedness and adaptation activities in Canada
Immediate
Geoscience knowledge products including expert advice, syntheses, data, information, peer-reviewed papers, maps, models, databases and tools are created and made publicly available
OUTPUTS
Supporting Adaptation in Permafrost Regions
Supporting Adaptation in Coastal Regions
Extreme Events
Glacier Mass Balance
PROJECTS
Conduct studies on the effects of a changing climate on geomorphic, earth surface, and related processes and dynamics.

STRATEGIC PRIORITY 4: GEOSCIENCE FOR SOCIETY

Open Geoscience Network

Why? To ensure that federal geoscience data and information are findable, accessible and re-usable.



Goals:

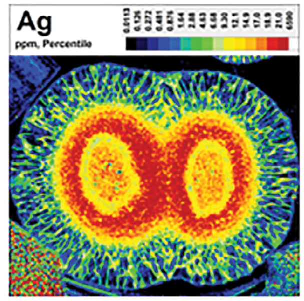
- Facilitate the preservation of corporate knowledge by ensuring access to applications/databases
- Improve research support activities by facilitating coordination of IM/IT services
- Boost research efficiency by facilitating collaboration and knowledge dissemination
- Align research and dissemination with government priorities
- Serve as Open Science point of contact for the GSC

IT Infrastructure	To ensure that information systems are in place and maintained to securely generate, store, manage and disseminate GSC data, publications, collections and knowledge. This Includes: • Short and long-term planning of IT-related infrastructure • Support of departmental initiatives such as digital transformation
Information Systems and Data	To ensure that geoscience data is managed throughout its lifecycle according to authoritative standards. This includes: • Tools to support data collection, storage, organization, management and field compilation • Enhancements to data models (i.e. surficial, bedrock and marine) • Development of workflows for authoritative corporate data repositories
Open Access and Public Engagement	To ensure that high quality authoritative geoscience publications are timely and freely accessible to Canadians. The public is aware of and makes use of GSC program outputs and has mechanisms to provide feedback. This includes: • Management of all GSC scientific publications (production and dissemination) • Communications (e.g. social media, GSC website)
Synthesis and Integration	To ensure increased knowledge (and access to) the geology of Canada as a whole through the integration of various data sets, using new and innovative methods, including for dissemination. This includes: • Development of new synthesis and integration tools, analysis techniques (AI, modeling, including predictive, 3D, and integrative models) • Interactive and dynamic dissemination methods and platforms
Earth Material Collections	To ensure that GSC physical collections are properly documented, preserved and curated. Life-cycle procedures are in place. This includes: • Earth material samples (hard rock, cores, tills, sands, fossils) collection and lifecycle management

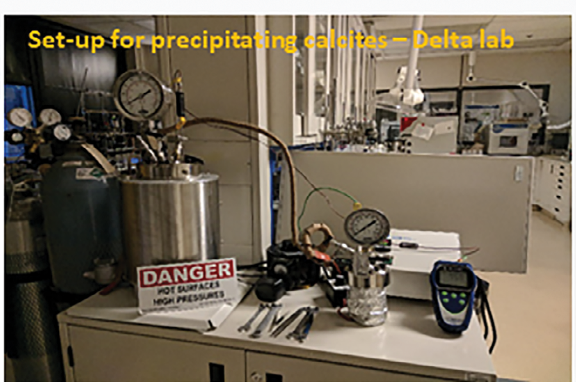
STRATEGIC PRIORITY 5: OUR SCIENCE, OUR PEOPLE

Science Laboratory Network

Why? To provide innovative lab-based research leadership and state-of-the-art analysis and interpretation for all GSC programs, and to increase effectiveness, connectivity, and efficiency in GSC labs



Project	Success Stories
Lab-based scientific innovations/ method development	• Lab scientists have developed analytical techniques using ColdBlock, a Canadian innovation that is a new, revolutionary geochemical technology for digesting solids with faster, more precise and safer results. It has applications throughout all facets of geochemistry and lab-based research projects. • A temperature calibration framework for clumped isotope analysis has been developed by lab scientists through precipitation of synthetic calcites. Clumped isotopes provide critical information on the temperature of paleofluid systems and are applicable in a wide range of geological research, including basin analysis, diagenesis, paleoclimate and ore deposit studies. • Lab scientists have developed a straightforward method to differentiate organics associated with oil sands process-affected water (OSPW) from those found naturally in groundwater in contact with the bituminous McMurray Formation. These developments contribute to environmental forensics of organic contaminants in Canada's oil sands region. • Organic geochemistry lab data have been included in thermodynamic modeling of hydrocarbon compositions in rocks in order to integrate geochemistry with chemical/reservoir engineering for more efficient hydrocarbon extraction. • Sensitive High Resolution Ion MicroProbe (SHRIMP) instruments lead the world in their ability to determine the age of microscopic mineral domains. In collaboration with Geoscience Australia, lab scientists have developed and released a beta-version of SQUID3, a platform-independent, open-source, Java-based application to replace existing obsolete software for SHRIMP data processing. Improved functionality will ensure the sustainability, future improvement, reliability and relevance of SHRIMP data from around the world.



Set-up for precipitating calcites – Delta lab

SQUID3: Next-generation data processing software for SHRIMP

Annex III: 2019–20 Geological Survey of Canada science program communication products

External vs. Internal	Specific type of publication	Number
External publications	External peer-reviewed publication published	451
Internal publications	GSC Open Files published	340
	GSC Maps published	46
	Other internal GSC publications	73
Other	New databases put online	132
	Webinars	3
	Interviews	227
	Press articles	9
	Tweets	530
	Presentations to industry / stakeholders (e.g., at open houses, conferences, workshops, meetings)	267
	Presentations made to indigenous associations / communities / partners	53
	Science-based briefing notes to senior LMS management (DG And Above)	9
	Presentations made to senior management (DG and above)	26
	Other (e.g., outreach videos, summary reports, updating guideline report, policy meetings)	23

To view GSC open geoscience publications please visit GEOSCAN: https://geoscan.nrcan.gc.ca/geoscan-index.html.

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